Ultrasonics 2021
Demo exercise 3

Submit your solutions to Axi Holmström (axi.holmstrom@helsinki.fi) at latest on 27.4. 23:59.
Necessary datasets:
https://www.dropbox.com/sh/opl68498jjfzf30/AACQmt0ZNxgPib5EHSVCbi1Ya?dl=0

Ultrasound phased array imaging - Synthetic aperture focusing

a) (2 points)

Unzip SAFT_exercise.zip into your computer hard drive. Open 'Plot_phased_array_b_scan_image__v2.m' in Matlab and run it to plot a B-scan image. This B-scan image represents a single element pulse-echo measurement in water by scanning over 128 elements of a phased array transducer. Locate two steel cylinders in water (location at scan axis and depth axis). Using the formula for a transducer near field (natural focus), calculate the minimum number of transducer elements (transducer aperture minimum size) needed to focus to the depth of each cylinder in the image. The transducer element size is 0.75 mm, pitch is 1 mm and center frequency is 2 MHz. Sound velocity in water is 1500 m/s. Why does the wave front scattered from the cylinders look curved?

b) (2 points)

Open Plot_phased_array_focused_b_scan_image.m. The code calculates focusing starting from the first A-line in the data from part a) (first A-line of focused dataset) using the aperture defined in the variable "aperture_size_pxls". Update the code to calculate focusing for the rest of the data by adding a for-loop to perform calculations starting from a-line 2, 3, 4, etc. Set the focal depth (variable "depth_mm") to the depth of the cylinders one at a time and observe how the image changes. Remember to use a wide enough aperture size calculated in part a). What is the lateral size of the cylinders in the images and how does the focusing depth affect this size?

Time reversal

Time-reversal (TR) is a technique to focus acoustic energy inside complex media. Time-reversal focusing requires impulse response from the target point. In the process, the forward-propagated signal is time-reversed ('flipped as mirror image') and transmitted back in the back-propagation scheme. Due to the reciprocity of the wave equation, the transmitted signal has the focal point at the target point.

1. Reciprocity principle

A) (1 point)

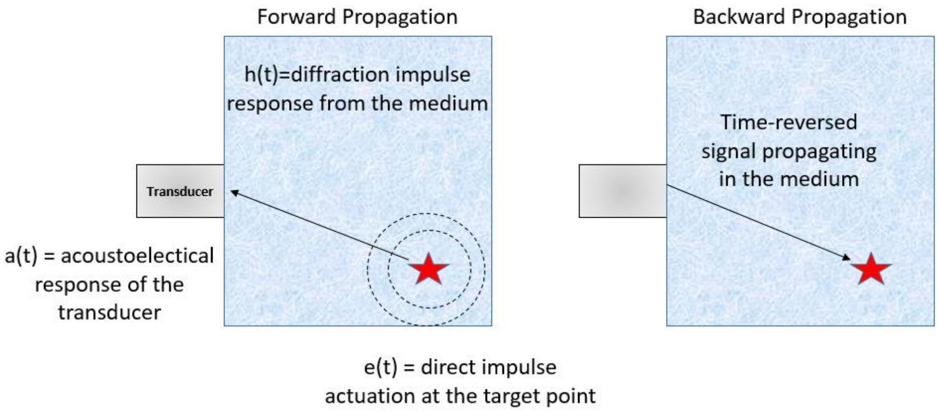
Derive the pressure at the target point in the back-propagation phase in the following time-reversal setup configuration by using Newhouse's and Furgason's notations [1]. Ideally, the result should be in the following form:

$$p(f) = TR(-f)A(f)H(-f)$$

In which

$$tr(t) = e(t) * h(t) * a(t)$$

Here, notation 'g(-x)' means 'time-reversed g(x)' and operation * is convolution.



[1] Newhouse, V. L., and E. S. Furgason (1984) Ultrasonic correlation techniques, In Research Techniques in Non-Destructive Testing, ed. R. S. Sharpe, Vol. 3, 101– 34, Academic Press, London.

Also explained in 'Ensminger, Dale, and Leonard J. Bond. (2011) Ultrasonics: Fundamentals, Technologies, and Applications, Third Edition, Taylor & Francis Group, 89-90'

B) (1 point)

$$p(z,t) = A\cos(k(z-ct))$$

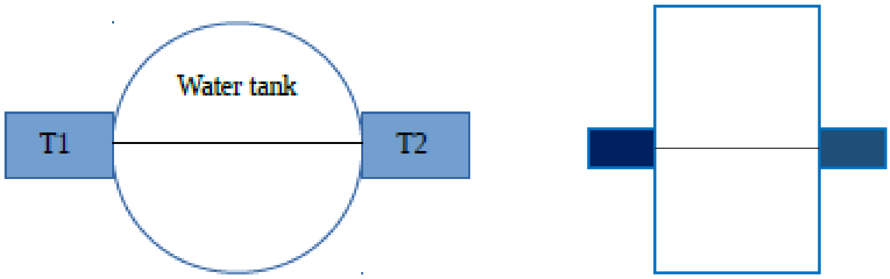
Time-reversal focusing is based on T-symmetry T: t → -t which arises from the acoustic wave equation containing only even order derivatives. This feature is also known as *reciprocity*. Show that both p(z,t) and p(z,-t) satisfy the 1-D wave equation.

C (1 point)

What is the wave length with 2 MHz central frequency in water with 1 kPa peak-negative-pressure?

2. **Processing and analyzing the experimental data**

In our example, we have conducted two spark excitations at two different locations in the water tank. Echoes have been recorded with two Langevin piezoelectric transducers (T1 and T2).



The recorded signals are attached (signal1-4.csv). The first column is time [s] and the second column is amplitude [V]. Signals 1 and 2 are from the first excitation and signals 3 and 4 are from the second. Signals 1 and 3 have been recorded with T1 and signals 2 and 4 have been recorded with T2.

A) (1 point)
What is the diameter of the water tank? What is the recorded central frequency? What sampling frequency was used?

B) (2 points)
Remove noise from the signals by filtering them with moving average filter or Savitzky-Golay filter. Time-reverse the signals by flipping the amplitude column in the up/down direction. In Matlab, use flipud function. In Python, use the function with the same name from Numpy-library. Plot filtered signals before and after time-reversing as subplots (two signals is enough).

3. Determining the focal region
(2 Points)
Calculate spatial-peak temporal-peak intensities for hydrophone (Brüel &Kjær, 8103) measurements in water. Find the data attached (pressure1-3.csv) from three different measurements. The first column is time [s] and the second is amplitude [V]. How could spatial-peak temporal-peak intensity be related to time-reversal focusing?

Acoustic levitator

Each task (see below) is worth 2 points.

1. Consider a single axis Langevin acoustic levitator consisting of a flat transducer and a flat reflector. The transducer plate vibration was measured in the resonant frequency with LDV: peak-to-peak amplitude 40µm and frequency $35kHz$.

   Calculate the optimal distance for the reflector and the maximum density of a small spherical sample that still levitates. (Hint: Gor'kov potential)

2. A phased array acoustic levitator consisting of 12 acoustic sources was built. When the sources were positioned 4 cm distance from the levitation spot, the heaviest material that could be levitated was Styrofoam ($\rho \approx 20kg/m^3$).

   The next iteration needs be able to levitate small pieces of rock ($\rho \approx 3000kg/m^3$). How many similar transducers are needed, if they can not be positioned any closer than 7 cm.

   (Hint: Gor'kov potential, geometric spread of point like transducer is inversely proportional to square of distance r)