IN5450/IN9450 Project III: MIMO Pulse-echo imaging

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Overview

The exercises in this project will be related to the topic of waveforms, Virtual Arrays, Multiple Input Multiple Output (MIMO) and pulse echo imaging using the Delay-And-Sum (DAS) algorithm. All the needed material is presented in the MIMO and Synthetic Aperture Focusing Technique (SAFT) lecture.

A presentation of 10-20 slides should be delivered. All code must be submitted and must be possible to run with a parameter-free script.

Setup

We will in this project consider an in-air acoustic pulse-echo setup with $N_{rx} = 32$ receivers and $N_{tx} = 2$ transmitters, all placed on the x axis as shown in Figure 1. The speed of sound is $c = 340$ m/s.

We will investigate data from two numerical experiments: A Time Division Multiple Access (TDMA) experiment and a Code Division Multiple Access (CDMA) experiment.

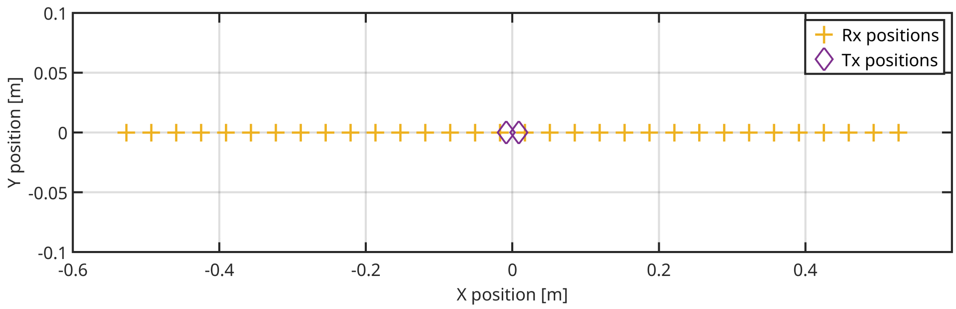

Figure 1: Transmitter and receiver positions

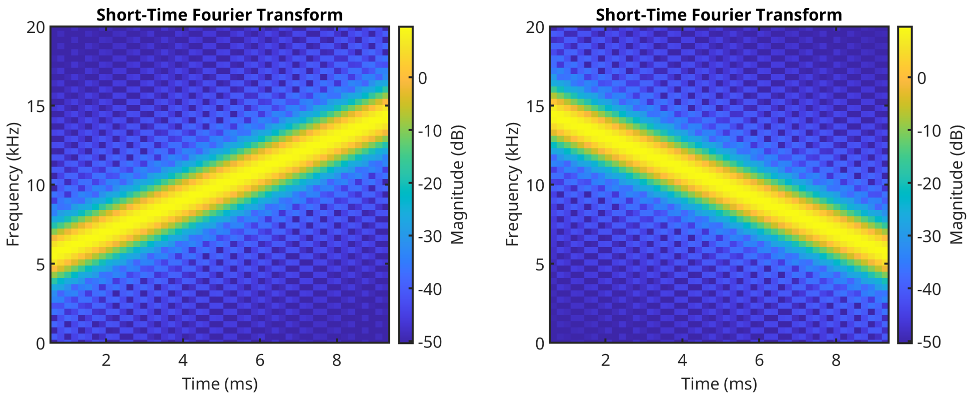

Figure 2: STFT of the LFM upchirp (left) and LFM downchirp (right)

The matlab mat file `mimo_project.mat` at the course web page contains the recorded timeseries from the two different simulations:

- The variable `tdma_data` contains the recorded timeseries from two transmits logged separately. The data are complex of size $[N_t, N_{rx}, N_{tx}]$.
- The variable `cdma_data` contains the recorded timeseries from two transmits transmitted simulateously. Each receiver then receives the echo from each transmitter at the same time (approximately). The data are complex of size $[N_t, N_{rx}]$.

The recorded timeseries are of length N_t and starts at $t = 0$. In addition, the mat file contains the Rx positions in `rx_pos`, the Tx positions in `tx_pos`, and the sampling frequency is stored in variable `fs` (in Hertz).

The transmitted signal is a Linear Frequency Modulated (LFM) pulse of pulse length T_p, with signal bandwidth of B, as follows

$$s_{Tx,up}(t) = \exp\left\{j2\pi((f_c - B/2)t + \alpha t^2/2)\right\}, \quad 0 \leq t \leq T_p \tag{1}$$

$$s_{Tx,down}(t) = \exp\left\{j2\pi((f_c + B/2)t - \alpha t^2/2)\right\}, \quad 0 \leq t \leq T_p \tag{2}$$

for the upchirp and downchirp respectively. α is the chirp rate related to the signal bandwidth as $\alpha = B/T_p$.

The programmed signal bandwidth is $B = 10$ kHz, the center frequency of the signal is $f_c = 10$ kHz, and the pulse length is $T_p = 10$ ms. The Short Time Fourier Transform (STFT) of the two waveforms are shown in Figure 2.

For the TDMA data, LFM upchirp is used in both transmits. In the CDMA data, LFM downchirp is used on the leftmost transmitter, and LFM upchirp on the rightmost transmitter.

All relevant system and geometry parameters are stored in the mat file using sensible variable names.

1 Pulse compression

Follow the waveforms-part in the lecture notes. Implement synthetic replicas of the transmit signals and a pulse compression algorithm using the cross correlation function. Remember that only positive lags should be kept after correlation. Also remember that the inputs should be complex and the output should be complex. Show code in the presentation.

What is the theoretical time-resolution (in seconds) in the sequence after pulse compression?

Select a single receive channel from one transmit of the TDMA data. Plot the absolute value of the timeseries before and after pulse compression. What is the difference? Explain.

How many reflectors are observable in the pulse compressed timeseries?

Investigate the pulse compressed timeseries, and estimate (approximately) the practical time-resolution. Compare with the theoretical.

2 Virtual Array

Construct the virtual array and plot the virtual array positions for one transmitter and for two transmitters.

What is the difference in the virtual array when only using one transmitter vs two transmitters?

Calculate the theoretical lateral resolution (in radians).

What is the approximate lateral resolution in meters at 4 m distance?

What is the axial resolution in meters?

3 Delay-And-Sum

Implement the Delay-And-Sum algorithm for pulse-echo imaging to be used on the simulated data. Use the true *bistatic* setup, that is, the actual transmitter and receiver locations. Use nearest-neighbour time interpolation. The complex pulse compressed data should be used in the DAS algorithm. Code must be shown in the presentation.

Select an imaging grid that is of size $X = [-5, 5]$ m, $Y = [0, 5]$ m. Select a suitable grid resolution in X and Y. Run DAS on the TDMA dataset and display the results as an image. Remember axis. It is preferred to show logarithmic intensity in dB in the image.

What is the X and Y position of the reflector? Describe what the image shows.

Measure the approximate axial and lateral resolution. Compare with the theoretical values. Any differences?

Run DAS on the TDMA dataset but only use one transmit sequence. Display in the same manner as above. What happened to the image when comparing with the full TDMA case? Explain.

Run DAS on the CDMA dataset. Remember that both transmit sequences are now recorded in the same timeseries (the CDMA data does not have a separate transmit dimension). Display in the same manner as above. What happened to the image when comparing with the full TDMA case? Explain. What is the level of the pollution? Why?

4 Extra (mandatory for IN9450 students)

Run DAS on the full TDMA dataset, now with Hamming tapering on the receive array and on the transmit waveform. Display and compare with the original full TDMA image. What is the difference? Explain.

Run DAS on the TDMA dataset but only use one transmit sequence, now with Hamming tapering on the receive array and on the transmit waveform. Display and compare with the original single transmit TDMA image. Does tapering solve the undelying problem with the image? Explain.

Run DAS on the full TDMA dataset, now using the virtual array element positions and assume that the phase center approximation holds (that is, no range correction). Display and compare with the original full TDMA image. What is the difference? Explain.