Introduction

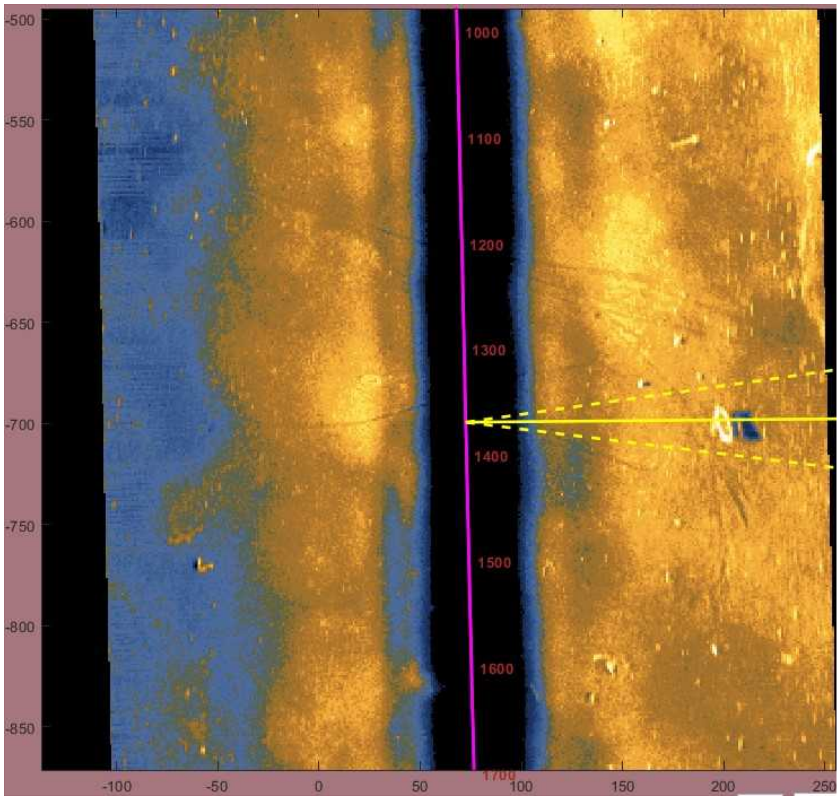

Figure 1: Sidescan sonar image of the scene

The exercises in this project will be related to sonar data collected by the HUGIN autonomous underwater vehicle. Figure 1 shows the recorded sonar data stacked in one line per ping and shown in a two-dimensional image as function of range (x-axis) and ping number (y-axis). This is called a sidescan sonar image.

We will consider a single ping (or pulse) with recorded timeseries from one horisontal receiver array with $N_h = 32$ hydrophones (receivers). The transducer that emits the pulse can be approximated to a point source situated in the middle of the receiver array.

The data file `sonar_ping.mat` at the course web page, is a matlab mat-file that contains the recorded timeseries from a single ping of sonar data as described above. The variables stored in the mat-file are listed in Table 1.

The length of the receiver array is $L = N_h d$, and the transmitter is assumed to be centered at the receiver array.

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

$$s_{Tx}(t) = \begin{cases} \exp(j2\pi\alpha t^2/2) & -T_p/2 \leq t \leq T_p/2 \\ 0 & |t| > T_p/2 \end{cases} \tag{1}$$

where α is the chirp rate related to the signal bandwidth as

$$\alpha = B/T_p \tag{2}$$

Note that the received timeseries are basebanded at reception (the carrier frequency has been removed). We have therefore taken out the carrier (center frequency) from the signal model.

Description	Variable	Units
Raw data	rawdata	
Sampling frequency	fs	Hz
Center frequency	fc	Hz
Bandwidth	bw	Hz
Pulse length	t_p	s
Element size	d	m
Sound speed	c	m/s

Table 1: Variables in the mat-file

a)

- What is the theoretical angular resolution of the system at the center frequency?
- What is the angular field of view of the system at the center frequency?
- What is the range (depth) resolution?

All answers must contain both the expression and the numeric value for this particular system.

Pulse compression

Pulse compression can be performed either by cross correlating the received signal with the transmitted

$$s_m(\tau) = \int s_{Rx}(t) s^*_{Tx}(t+\tau) dt \tag{3}$$

or equivalently, using the Fourier transform

$$s_m(\tau) = \mathcal{FT}^{-1} \left\{ \mathcal{FT}\{s_{Rx}(t)\} \mathcal{FT}\{s_{Tx}(t)\}^* \right\}. \tag{4}$$

b)

See Fig. 2 to verify your results in this task.

- Implement a pulse compression algorithm in matlab.
- Use Eq. (1) to generate a synthetic replica of the transmitted signal. Code must be presented.
  - (!) Remember to only positive delays if you use the matlab-function `xcorr`.
  - (!) Remember to complex conjugate if you use the Fourier transform based version.
- Pulse compress the rawdata. Choose a single channel, plot the magnitude of the particular channel before and after pulse compression. Plot the data zoomed in at sample number 4000 to 4400.
- Describe the difference between the raw data and the pulse compressed data. Explain why there is a difference.

Beamforming

c)

- **Implement the Delay-And-Sum beamformer for nearfield imaging in two dimensions.** Choose an output grid that matches the field of view of the system and the maximum range, similar to a sectorscan sonar. Choose a grid resolution better than 20 cm in each dimension. The data is

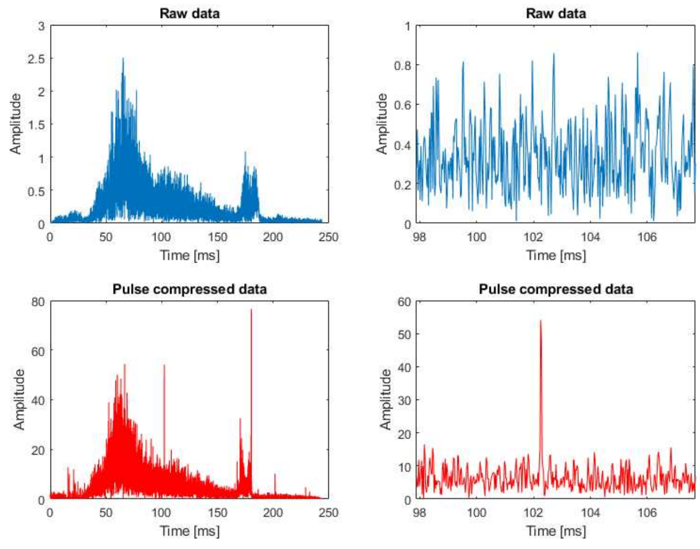

Figure 2: Example of what to get in **b)**.

basebanded. They must be mixed up to center frequency before sum. This is done by multiplying the delayed signal with the complex exponential

$$\exp(j2\pi f_c \tau) \tag{5}$$

where τ is the calculated time delay for the particular pixel in the scene. It is important that the interpolation is done on baseband data before multiplication with the complex exponential. Code must be presented.

- Run the delay-and-sum algorithm on the raw data and on the pulse compressed data.
- Display the sonar data before and after pulse compression, and before and after beamforming (four images) using relative intensity in dB-scale in cartesian coordinates. The intensity in dB scale is

$$I_{dB} = 10\log_{10}(I) = 20\log_{10}(A) \tag{6}$$

where $I = A^2$ is intensity (relative) and A is amplitude or magnitude. All plots should have meters on the range axis. The beamformed images should preferably have meters on both axis.

- What is the difference before and after beamforming? Explain.
- What is the difference before and after pulse compression? Explain.
- Consider the pulse compressed beamformed (sectorscan sonar) image. There is a target at approximately 130 m range. What is it? How large is it in meters?