

# INF4480 Project III: Spectral estimation

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## Introduction

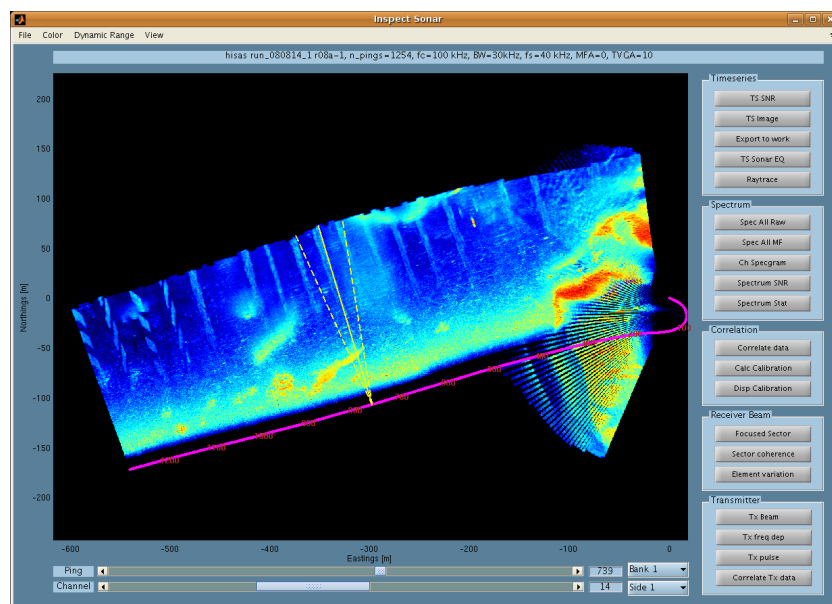


Figure 1: Georeferenced sidescan sonar image (or mosaic)

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 after pulse compression (matched filtering) and beamforming (by delay-and-sum). The range profile from each ping has been rotated and georeferenced relative to each other. This is called a sidescan sonar image. The yellow lines indicates the particular ping to be used in this exercise.

The sonar geometry is shown in Figure 2. We will consider a single ping (or pulse) with recorded timeseries from one horizontal receiver array with  $N_h = 32$  hydrophones (receivers).

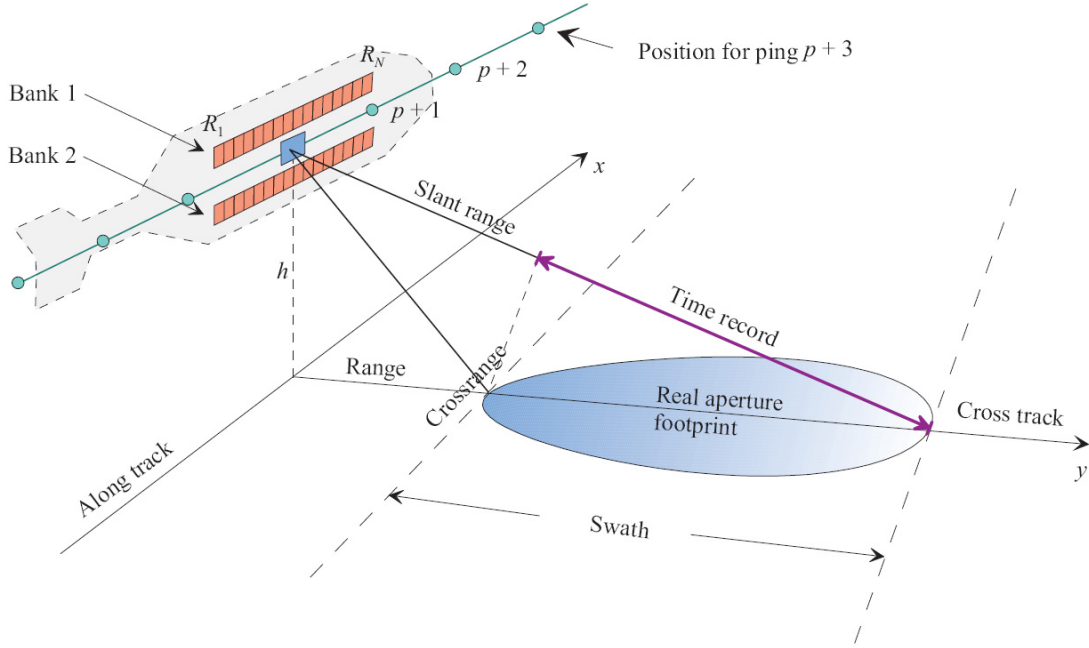


Figure 2: Sonar geometry

The data file `sonardata4.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 variable `data` contains a complex matrix of size  $[N_t, N_h]$ , where  $N_h = 32$  is the number of hydrophones, and  $N_t$  is the number of time samples. The sampling frequency is stored in variable `fs` (in Hertz). The start time for the recordings is zero.

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

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

where  $\alpha$  is the chirp rate related to the signal bandwidth as

$$\alpha = B/T_p \quad (2)$$

The programmed signal bandwidth was  $B = 30$  kHz, and the center frequency of the signal was  $f_c = 100$  kHz. 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.

# 1 Spectral estimation

## Exercise 1 A

Create an array out of the following selection:

- Channel 14
- Start sample  $M = 1200$
- Number of samples  $N = 1024$

Assume that the sequence is WSS within the data window.

Implement, calculate and plot the following spectral estimates:

- The periodogram
- The modified periodogram with a window of choice
- The Welch method with segment size  $L = 256$  and overlap  $D = L/2$
- The multitaper spectral estimator using matlab's function `pmtm`. Choose the order of the method (should be larger than 3).

See the lecture notes for details about the methods. Matlab source code must be written in the presentation. Do not use matlab's `periodogram` and `pwelch`.

The plots should have frequency in kHz on the x-axis, and Power spectral density in dB on the y-axis. Remember proper normalisation (such that the y-values from all the spectral estimators can be compared).

1. Does bias reduction help? Explain (from data).
2. Does variance reduction help? Explain (from data).

The transmitted (ideal) signal has a flat frequency response within the bandwidth of 30 kHz. There should be no signal outside the frequency band.

1. Estimate the true bandwidth (from guessing when the signal energy has dropped below 6 dB from the passband)
2. What is wrong with the spectrum (compared to the ideal spectrum)?

## Exercise 1 B

Create an array out of the following selection:

- Channel 9
- Start sample  $M = 7000$
- Number of samples  $N = 2048$

Assume that the sequence is WSS within the data window.

Calculate and plot the following spectral estimates:

- The periodogram
- The modified periodogram with a window of choice
- The Welch method with segment size  $L = 256$  and overlap  $D = L/2$
- The multitaper spectral estimator using matlab's function `pmtm`

This part of the signal is dominated by additive noise and interference (lines from other sources).

1. Does bias reduction help? Explain (from data).
2. Does variance reduction help? Explain (from data).
3. What is the consequence of variance reduction?

## 2 Spectrogram analysis

### Exercise 2 A

Create an array out of the following selection:

- Channel 14
- Start sample  $M = 400$
- Number of samples  $N = 8192$

The sequence has time-varying statistics within the data window.

Implement the short-time Fourier transform (STFT) method (or spectrogram).

- Choose the modified periodogram with a window (taper) of choice.
- Choose a segment length of  $L = 64, 128, 256, 512$
- Zeropad each segment with a factor 4

Follow the method description in the lecture notes. Display the STFT as colorcoded image in dB, with frequency in kHz on the y-axis and time in ms on the x-axis. Show at least 50 dB dynamic range. Matlab code has to be written in the presentation. Compare the four STFTs.

1. What is the consequence of choosing segment length?
2. The chips seen around the time-frequency representation (especially from 100 ms to 200 ms, are from other interfering sensors. What is the length of the chips (in ms)? Are the frequencies constant from chip to chip?