ECEN 444: Matlab Assignment 2

Due March 26, 2009

1 Overview

In this assignment, we will explore the properties and applications of the cross correlation and autocorrelation. Cross correlation is often used to find one signal "buried" in a another signal with an unknown delay. While the autocorrelation is often used to estimate the power-spectral density of a signal.

When working on the project, please follow the instructions and respond to each item listed. Your project grade is based on: (1) your Matlab script, (2) your report (plots, explanations, etc. as required), and (3) your final results. Several example Matlab script files have been posted on the website. The desktop version of Matlab also includes a script editor which highlights the syntax.

The project report should include all your scripts and plots. It is often easier to combine these using Microsoft Word or Powerpoint. For example, you can copy/paste figures from MATLAB into these applications. You must clearly display the associated problem number and label the axes and on your plots to get full credit. Submission can be done electronically in PDF format or on paper.

2 Exercises

2.1 Ultrasonic Measuring Tape

After you graduate, you begin working at Ultrasonics Unlimited with an engineer from Texas University. Your goal is to design a system that transmits some ultrasonic waveform, listens for the echo from nearby reflecting objects, and determines the range to the nearest reflecting object. Let us assume that the system operates in discrete-time with a sampling frequency of 100 KHz or $T = 10^{-5}$s. Let $x(n)$ be the transmitted waveform and

$$y(n) = \sum_{i=1}^{P} a_i x(n - k_i).$$

be the received waveform consisting of P reflections each with delay k_i and coefficient a_i.

To find the delays and coefficients, one can cross correlate $y(n)$ with $x(n)$ because

$$\begin{aligned} r_{yx}(l) &= \sum_{n=-\infty}^{\infty} \sum_{i=1}^{P} a_i x(n - k_i) x(n - l) \\ &= \sum_{i=1}^{P} a_i r_{xx}(k_i - l). \end{aligned}$$

If $r_{xx}(0) \gg r_{xx}(n)$ for $n \neq 0$, then one can find the delays k_i by finding the peaks in $r_{yx}(n)$.

(a) The engineer from TU suggests that you choose

$$x(n) = \begin{cases} \cos(2\pi f n) & \text{if } n = 0, \ldots, 99 \\ 0 & \text{otherwise} \end{cases}$$

with $f = 0.1$. Plot this signal and the autocorrelation $r_{xx}(n)$ (try `help xcorr`) using `stem`. Try using `[ac,lags]=xcorr(x)` to automatically get the correct time indices your $r_{xx}(n)$ plot.

(b) You remember that real radars use "Chirp" signals estimate distance. A linear chirp is a signal whose frequency increases with time. So you suggest the signal

$$x(n) = \begin{cases} \cos\left(2\pi \frac{n}{800} n\right) & \text{if } n = 0, \ldots, 99 \\ 0 & \text{otherwise} \end{cases},$$

where the frequency $\frac{n}{800}$ varies from 0 to $\frac{1}{8}$ cycles per sample. Plot this signal and the autocorrelation $r_{xx}(n)$ using `stem`. Make sure you choose the time indices correctly for the $r_{xx}(n)$ plot.

(c) Based on your plots, which signal is more suited to this application and why?

(d) Simulate the performance of your ultrasonic measuring tape for both signals. Assume that

$$y(n) = \frac{1}{2} x(n - 2000) + z(n)$$

where $z(n)$ is standard Gaussian noise (see `help randn`) of length 10000. Use largest value of $r_{yx}(n)$ to estimate the delay (see `help max`). Try 10 runs with different noise. Which signal is better?

(e) On the class website, the signal "ultra_test.txt" contains a test vector based on the the Chirp signal. Use this signal (try `help load`) to estimate the distance to the nearest reflecting object assuming the speed of sound is 1000 feet per second.

2.2 Autocorrelation of Periodic Signals

The autocorrelation of a period signal is also periodic. The peak with the smallest non-zero value should give a good estimate of the period of the original signal. This can be used to estimate the pitch of a voice recording. Record yourself singing a single note for roughly 1 second at 8 KHz sampling with 16 bit resolution. Let this waveform be $x(n)$.

(a) Break this signal into 40 ms (i.e., 320 sample) blocks. For each block, compute the autocorrelation $r_{xx}(l)$ and find the index of maximum value (see `help max`) for $l = 16, \ldots, 100$.

(b) The pitch estimate for each block is inversely proportional to the index of the autocorrelation peak. Plot the pitch estimate for each block versus the block number. Estimate the frequency in Hz of the note you were singing.

2.3 Helpful hints

It is possible to record sound with Matlab (see `help audiorecorder`). Here is a short (untested) example:

```
rec = audiorecorder(8000,16,1);
record(rec,2);
signal = getaudiodata(rec);
```

If you have trouble with this, you can always cut out a piece of the example file on the web:

```
raw = wavread('speech0.wav');
signal = raw(14700:18700);
```

It is also worth knowing that you can delay a signal of short duration using the following:

```
xdelay = zeros(1,10000);
xdelay(2001:2100) = x(1:100);
```