

M2 PI / ED S3M DataFit – Data acquisition and analysis

Module 2: Data analysis and modelling – Tutorial / workshop 3

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Introduction

This workshop will not be formally assessed, but you will need to show that you have completed all the problems outlined in this worksheet. These are designed to give you some practice in data analysis, and are an essential part of the course.

These exercises should be carried out with the scientific data analysis software IGOR Pro, though some of the simpler exercises can be done by hand.

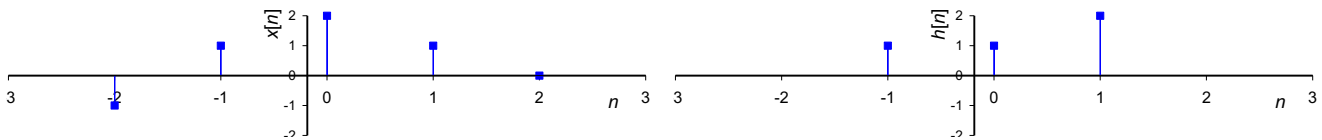
To solve these problems, you can use online help and ask the postgraduate tutor to get you started.

You will also need to refer to your notes from the lectures.

Convolution – by hand

1. Determine and sketch the response $y(t)$ of the LTI system with impulse response $h(t) = e^{-at}u(t)$, $a > 0$ to the step input signal $x(t) = u(t)$.

2. Find $y[n] = x[n] * h[n]$ for the signals shown below



Convolution – using a computer¹

1. Write a program that calculates $y[n] = x[n]*h[n]$, where $y[n]$ is 598 samples, $x[n]$ is 500 samples, and $h[n]$ is 99 samples.

2. Generate an impulse response, $h[n]$, according to the algorithm below (note this is not written in Igor programming language). (This is the filter kernel for a "low-pass windowed-sinc" filter. When convolved with an input signal, this filter passes sinusoids that have fewer than 25 cycles in 500 samples, and blocks sinusoids with a higher frequency. Make a plot of this signal.

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for i = 0 to 98
    h[i] = 0.31752 * sin(0.314159 * (i-49.00001)) / (i-49.00001)
    h[i] = h[i] * (0.54 - 0.46 * cos(0.0641114 * i))
next i
    
```

3. Test your program by convolving $h[n]$ with the signal described below. What should the output of your program be in response to this signal? Why?

$x[n] = 1$ for $n = 0$
 $x[n] = 0$ otherwise

¹ "The Scientist and Engineer's Guide to Digital Signal Processing", copyright ©1997-1998 by Steven W. Smith.

4. Generate a more complicated test signal, $x[n]$, that consists of two sinusoids added together. The first sinusoid will have an amplitude of 1, and make 6 complete cycles in the 500 samples. The second sinusoid will have an amplitude of 0.5 and make 44 complete cycles in the 500 samples. Make of plot of this signal.
5. Test your convolution program by filtering the signal you created in 4, with the filter kernel you created in 2. Plot this signal. Has the filter passed the lower frequency signal, while blocking the higher frequency signal? Comment on its effectiveness.
6. Turn the filter kernel into a high-pass filter by changing the sign of all the samples, and then adding one to sample 49. Test this high-pass filter in the same way as step 4.

Correlation

The exercise looks at two different ways of detecting a known waveform in a noisy signal. The waveform to be detected is an exponentially decaying pulse. The first detection method is to threshold the first difference of the signal. The second method is to threshold the correlation of the signal with the known waveform.

1. Generate a 600 sample test signal, containing three target pulses:

$$\begin{aligned}x[n] &= \exp(-(n-100)/15), & \text{if } 99 < n < 160 \\ &= \exp(-(n-300)/15), & \text{if } 299 < n < 360 \\ &= \exp(-(n-500)/15), & \text{if } 499 < n < 560 \\ &= 0, & \text{otherwise}\end{aligned}$$

2. Generate a 600 sample signal of normally distributed random noise with mean = 0, and SD = 1.
3. Generate four test signals with signal-to-noise ratios (SNRs) of 50, 10, 5, and 2.5. Do this by adding the signal from step 1, with an appropriately scaled version of the noise from step 2. For this problem, we will define the SNR to be equal to the peak amplitude of the target waveform (which is one), divided by the standard deviation of the noise. Plot these four test signals.
4. Calculate and plot the first difference of the four test signals.
5. Calculate and plot the correlation of each of the four signals with the 60 point target signal. (Check your program by making sure that the peaks have the proper symmetry).
6. Based on your results, estimate the minimum SNR that the signal must have in order to reliably detect the target by:
 - a. a visual inspection of the waveform
 - b. thresholding the first difference
 - c. thresholding the correlation signal