Research Centre for Non-Destructive Evaluation

Engineering Doctorate Programme

Introduction to Signal Processing for NDE

Coursework

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RCNDE EngD Programme: Introduction to Signal Processing - Coursework.

This coursework is in two parts:

Part 1 will be done in a Faculty computing laboratory. It will take up the afternoons of the one-week work programme and will consist of a set of short exercises and the preparation of reports on your work.

Part 2 consists of two more substantial exercises with an emphasis on the applications of signal processing to NDE. It should be done in your own time, after the one week work programme. A report of between 5 and 10 pages should be prepared on each exercise and submitted to the course organiser by email before the agreed deadline. It is expected that you will require around 20 hours to complete part 2.

Assessment

The short reports from part 1 will attract a maximum aggregate mark of 50%. Each of the two reports from part 2 will attract a maximum mark of 25%. The three marks will be summed to give an overall percentage mark which will then be expressed as letter grades:

A	≥80
B	70 – 79
C	60 – 69
D	50 – 59
E	<50 (fail)

PART 1:

Format and Purpose

This part of the coursework consists of a set of short exercises which are designed to enable you to:

- Gain familiarity with basic procedures for digital signal processing which are relevant to the field of non-destructive evaluation.
- Practice these procedures using Matlab.
- Identify aspects of the course that you do not understand.
- Receive tuition to assist your understanding.
- Prepare brief reports on each exercise.

Reporting

You should prepare a *brief* and *concise* report for each exercise. Each should be one, or not more than two, pages in length and should contain a title for the exercise, a statement of your procedure (could be bullet points), appropriate Matlab code listing/code snippet, results in graphical form, and a brief commentary on your results (one or two sentences).

Description of Files for RCNDE Signal Processing Course Exercises.

All files will open with Excel, Notepad and by using the “importdata” command in MATLAB. The array is easier to work with if you transpose it after import, for example:

```
sig = importdata('file.txt');
sig = sig.';
```

Ex1_1_trend1.txt, Ex1_1_trend2.txt and Ex1_1_trend2.txt

These files are for exercise 1.1, each one contains one column of data which has a different trend.

Ex1_8_interp.txt

This file is for use with exercise 1.8, it contains one column of data corresponding to the amplitude of an ultrasonic signal sampled at 40MHz.

Ex1_9.txt, Ex1_10.txt, Ex1_11.txt, Ex1_12.txt, Ex1_13.txt, Ex1_14.txt, Ex1_15.txt

These files are for use with exercises 1.9 – 1.15, each one contains two columns of data, the first column corresponds to time in seconds; the second corresponds to the amplitude of the signal at that time in volts.

Ex2_1.txt

This file is for use with exercise 2.1; it contains one column of data corresponding to the amplitude of an ultrasonic signal sampled at 40MHz. **Note that the reflection coefficient between composite and water is +0.53 or -0.53, depending on the medium of incidence.**

Ex2_2_xt.txt and Ex2_2_yt.txt

These files are for use with exercise 2.2; each one contains a 1024 point time domain signal which has been sampled at 40kHz, Ex2_2_xt.txt corresponds to the first record (x1(n)) and Ex2_2_yt.txt corresponds to the second record (x2(n)).

THE EXERCISES FOR PART 1.

Trend removal and coherent averaging

E1.1. You will be provided with three signals each with a different trend. Remove the trends.

E1.2. Generate M random noise records of N samples each, then apply coherent averaging to them. Quantify the noise standard deviation before and after averaging; compare it with the expected value of $\sqrt{M}$.

Correlating signals

E1.3. Fill a 1024-point array (A) with two cycles of a cosine; do the same with a second array (B). Form the product of the arrays and estimate its integral numerically. Plot A and B and the product; print the numerical value of the integral in the plot.

E1.4. Repeat E3 with the difference that the second array, B, contains 20 cycles of a cosine. Comment on the result.

E1.5. Repeat E3, but this time the array B must contain two cycles of a sine wave, rather than a cosine. Comment on the result.

E1.6. Write a program to generate the cross-correlation and auto-correlation functions of figures 3 and 4 in chapter 4 of the course notes. Try this with, and without, normalisation. (Matlab provides a correlation function: here, write your own.)

Use of the FFT

E1.7. Form 16-point arrays of the form

$$A \cos nk \frac{2\pi}{N}$$

and

$$B \sin nk \frac{2\pi}{N} \qquad (\mathrm{N} = 16).$$

with various values of A, B and the harmonic number k. Calculate the FFT and print the real and imaginary parts of the complex output array. Comment on the result.

E1.8. You will be provided with an ultrasonic signal digitised at the relatively low sampling frequency of 40 MHz. Use the FFT in an interpolation procedure to over sample the signal up to an effective sampling frequency of 160 MHz.

E1.9. You will be provided with a digitised ultrasonic signal which has been distorted with two forms of interference – random near-white noise, and a single interfering radio frequency. Use the FFT to calculate the modulus frequency spectrum of this signal. Compare this with the original time-domain waveform, and comment on the comparison.

E1.10. On the basis of section 5.7 of the course, apply a single-pole filter to the noisy waveform and then re-plot both the time-domain and the frequency-domain representations of the ultrasonic signal. Assume that the filter cut-off frequency is 0.2 f_s.

E1.11. The purpose of this exercise is to practice convolution in the time-domain. Use time domain convolution to filter the noisy ultrasonic signal of E9, following the method of section 6.2 of the course notes. If the cut-off frequency is f_0 and the sampling frequency is f_s, then a suitable impulse response will be:

$$h(n) = e^{-n2\pi f_0/f_s}$$

Digital filters

E1.12. Repeat E11, the exercise to filter the noisy ultrasonic signal, but this time using the digital filter of equation 109 in section 12.6 of the course notes.

E1.13. Try to achieve an equivalent filtering result using the moving average filter of section 13.1 – think carefully where to put the first zero of this filter and so what its impulse response length should be.

E1.14. Experiment on your signal with the band-pass and high-pass filters of section 13.2.

E1.15. Design a notch filter, based on section 13.4, which will remove the interfering radio frequency component from your signal.

PART 2:

Format and purpose

This part of the coursework consists of two more substantial exercises which will enable you to:

- Carry out work which requires the application of knowledge and skill in signal processing to two important applications of acoustic techniques in NDE.
- Prepare reports on the work, to a professional standard.

Reporting

For each exercise you should prepare a report of between 3 and 8 pages. It should include:

- A statement of the problem to be solved and its context. A diagram is often useful here.
- Details of the methods used – you may use references and/or refer to the course notes. There is no need to repeat algebraic derivations in the notes.
- Results
- Discussion
- Conclusion

THE EXERCISES FOR PART 2.

E2.1. NDE of an aerospace composite component.

You will be provided with a digitised version of an ultrasonic A-scan line from an aerospace carbon fibre reinforced composite (CFRC) panel of thickness 4mm. The record length is 256 points, sampled at 40MHz. At the beginning of the record you will see an echo from the front wall of the panel, and at the end you will see the echo from the back wall. These two echoes are not of the same shape due to the frequency dependent attenuation in the component. Now this attenuation is significant as an indicator of component quality and it would be useful to quantify the attenuation coefficient as a function of frequency. This is the object of this exercise.

Use appropriate window functions to extract the front and back wall echoes as separate signals, each in its own array. Then use the FFT to obtain the modulus of the frequency response that represents the change in shape between the front and back wall echoes. From this frequency response, calculate the attenuation coefficient (Nepers per metre) for the sample.

Note that the reflection coefficient between composite and water is +0.53 or -0.53, depending on the medium of incidence.

E2.2. An acoustic emission experiment.

It is possible that acoustic emission measurements could provide a means to monitor the condition of parts of complex plant. Comparison of emissions from more than one position could be used to assess the propagation of acoustic signals from one position to another. This exercise investigates this possibility through a simulation.

You will be provided with two signal records which represent acoustic emissions from two positions in a plant. Each record consists of a 1024 point time domain sequence sampled at 40kHz. The first record, $x1(n)$, consists of (almost) white noise, and the second, $x2(n)$, represents this noise after it has been filtered by propagation through plant components.

Estimate the standard deviation of the sequence $x1(n)$ and calculate its auto correlation function (ACF); comment on the result. Next, calculate the cross correlation function between $x1(n)$ and $x2(n)$ to obtain the impulse response that represents propagation between the two recording positions; what is the time delay? Finally, use the FFT to estimate the frequency response of the transition, again commenting on the result.