University of Calgary

Schulich School of Engineering

Department of Electrical and Computer Engineering

Enel 563 Biomedical Signal Analysis

Final Examination

Wednesday, 16 December 2008, ENC 123

3:30 − 6:30 p.m. (180 minutes)

Total Marks: 50

Instructions:

1. This is a closed-book, closed-notes exam.
2. Calculators with text/program storage capabilities are not allowed.
3. Answer all questions.
4. In case of problems requiring numerical or algebraic manipulation, show all steps clearly.
5. In case of problems requiring descriptive answers, provide clear statements in point form; long essays are not required.
6. In case of problems requiring algorithms, provide the reason or logic for each step.
7. Specify units or dimensions when appropriate.
8. In drawing plots of signals, spectra, etc., label the axes clearly.

Question 1:

Describe the events in the cardiac system that cause

(a) the components of the first heart sound (S1), and

(b) the components of the second heart sound (S2).

Describe an abnormal condition that could cause

(c) a systolic murmur (SM), and

(d) a diastolic murmur (DM).

Draw a schematic representation of the phonocardiographic (PCG) signal and the corresponding electrocardiographic (ECG) signal over two cardiac cycles and label the PCG signal with the parts related to S1, S2, SM, and DM.

(4 marks)

Question 2:

A discrete-time signal $x(n)$ is passed through a linear shift-invariant filter with the impulse response $h(n)$.

Write the full expression that gives the output $y(n)$ in terms of $x(n)$ and $h(n)$.

Starting with the basic definition of the $z-$transform, derive the relationship between the $z-$transforms of $y(n)$, $x(n)$, and $h(n)$.

(4 marks)

Question 3:

A researcher is developing methods to extract features from electrocardiographic (ECG) signals to distinguish between normal beats and premature ventricular contractions (PVCs).

Draw typical waveforms of the two types of beats and explain the major differences between them in qualitative terms.

Propose TWO quantitative measures or features to characterize the differences between normal beats and PVCs. Give an equation or a step-by-step algorithm to compute EACH feature.

(6 marks)

Question 4:

(a) A filter is specified to have a zero in the z domain at $z = 1$.

(i) Derive the transfer function $H_1(z)$ of the filter.

(ii) Derive the impulse response $h_1(n)$ of the filter.

(iii) Is this a lowpass, highpass, bandpass, or band-reject filter?

(b) Another filter is specified to have a double-zero (or two zeros) at $z = -1$.

(i) Derive the transfer function $H_2(z)$ of the filter.

(ii) Derive the impulse response $h_2(n)$ of the filter.

(iii) Is this a lowpass, highpass, bandpass, or band-reject filter?

(c) A researcher uses the two filters $H_1(z)$ and $H_2(z)$ as above in cascade (series).

(i) Derive the transfer function $H(z)$ of the combined filter.

(ii) Derive the impulse response $h(n)$ of the combined filter.

(iii) Draw the pole-zero plot for the combined filter.

(iv) Draw the signal-flow diagram for the combined filter.

(v) Is this a lowpass, highpass, bandpass, or band-reject filter?

(10 marks)

Question 5:

Using continuous-time and continuous-frequency representation, the fraction of the energy of a signal $x(t)$ in the frequency band $[f_1 : f_2]$ Hz is given by

$$E_{f_1:f_2} = \frac{\int_{f_1}^{f_2} |X(f)|^2 \, df}{\int_0^{\infty} |X(f)|^2 \, df} .$$

Here, $X(f)$ is the Fourier transform of the signal $x(t)$ being processed.

A researcher obtains a sampled version $x(n)$ of the signal $x(t)$ with the sampling frequency $f_s = 1000$ Hz. The number of samples in the signal is $N = 1900$. The researcher then pads the signal with zeros to increase the length to $M = 2048$ samples and applies the fast Fourier transform (FFT) routine to obtain the discrete Fourier transform (DFT) $X(k)$ of the signal.

The researcher wants to compute the fractions of the energy of the signal in the frequency bands $[0 : 50]$ Hz, $[51 : 100]$ Hz, and $[101 : 400]$ Hz.

Help the researcher by writing an algorithm to compute the three fractions. Ensure that you give the index of the DFT array for each frequency listed above.

Sketch a schematic representation of the spectrum $X(k)$ over the $M = 2048$ samples in the DFT array. Indicate all of the frequency bands required to compute the three fractions of energy, in terms of the frequency in Hz and the index of the DFT array.

(6 marks)

Question 6:

A student new to the field of biomedical engineering approaches you seeking assistance to develop methods to analyze the relationship between the force produced by contracting a muscle and the corresponding electromyographic (EMG) signal. Help the student by providing detailed responses to the following questions and requests:

(a) How can one acquire EMG signals corresponding to different levels of force?

(i) How many electrodes are required?

(ii) Where and how should the electrodes be placed?

(iii) How can one get another signal or variable that is directly proportional to the force?

(iv) What should be the settings for the bandwidth of the filters for the EMG signal?

(v) What should be the settings for the bandwidth of the filters for the force signal?

(vi) What should be the sampling frequency?

(vii) Give a step-by-step experimental procedure to acquire the required signals.

(viii) Draw a schematic diagram to illustrate the expected nature of the EMG and force signals. (6 marks for part (a))

(b) (i) What are the precautions to be taken in recording the signals?

(ii) List one potential source each for random noise, structured noise, and physiological artifact that could corrupt the EMG signal.

(iii) For each source of noise or artifact that you identify, recommend a procedure to prevent the same.

(iv) For each source of noise or artifact that you identify, recommend a post-acquisition procedure to remove the same. (6 marks for part (b))

(c) (i) What kind of measures or parameters may one derive from an EMG signal so that the measures vary in proportion to muscular force?

(ii) Give equations to define THREE parameters that are suitable for this purpose. For each parameter, give a step-by-step procedure to compute the parameter from the EMG signal.

(iii) Explain the expected relationships between the three parameters that you recommend and muscular force. Draw a plot with the force on the abscissa (x-axis) and the proposed parameters on the ordinate (y-axis). (8 marks for part (c))

(20 marks)

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