University of Calgary

Schulich School of Engineering

Department of Electrical and Computer Engineering

ENEL 563 Biomedical Signal Analysis

Final Examination

Saturday, 12 December 2009, ENC 123

8:00 – 11:00 a.m. (180 minutes)

Total Marks: 50

Instructions:

1. This is a closed-book, closed-notes exam.
2. No calculator or electronic device of any kind is permitted in the exam.
3. Answer all (seven) questions.
4. For questions requiring numerical or algebraic manipulation, show all steps clearly.
5. For questions requiring algorithms, provide the reason or logic for each step.
6. Specify units or dimensions when appropriate.
7. When drawing plots of signals, spectra, etc., label the axes clearly.

Question 1: (a) Draw a schematic graphical representation of a normal electrocardiographic (ECG) signal over one cardiac cycle. Identify all the waves and their typical durations. Identify the isoelectric parts of the signal.

(b) Draw an ECG signal with a wide and jagged QRS complex.

(c) Draw an ECG signal with an elevated ST segment.

(d) Draw an ECG signal with a depressed ST segment.

(4 marks)

Question 2: A biomedical signal sampled at 400 Hz with no aliasing error. The signal is known to contain power-line artifact at the fundamental frequency of 50 Hz and all of its harmonics up to and including the maximum frequency present in the signal. Draw the unit circle in the $z-$domain and show the positions of the zeros of a comb filter to remove the artifact. Mark the angle and frequency of each zero. (You do not have to derive the transfer function of the filter.)

(4 marks)

Question 3: Two discrete-time filters are specified in terms of their impulse responses as

$$h_1(n) = \delta(n) + \delta(n-1) + \delta(n-2) + \delta(n-3)$$

and

$$h_2(n) = \delta(n) - \delta(n-1).$$

The two filters are used in series to filter a signal. Derive and plot the impulse response.

Derive the transfer function and frequency response of the combined filter.

(6 marks)

Question 4: In an experiment on synchronized averaging, a researcher has available multiple observations of a noisy signal, expressed as $y_k(n)$, with $k = 1, 2, \ldots, M$ representing the ensemble index, and $n = 1, 2, \ldots, N$ representing the time-sample index. Here, M is the number of observations of the signal available, and N is the number of the time samples in each observation of the signal.

(a) Give an equation to define the output of the synchronized averaging procedure. Specify the range of the values of any index used in your answer.

(b) Give an equation to compute the averaged Euclidean distance between the output and each observation of the noisy input signal.

(6 marks)

Question 5: Draw a block diagram representing the various steps in the Pan-Tompkins method to detect QRS complexes in ECG signals. Explain the purpose and nature of each step in the procedure, including detection of the peaks in the output corresponding to the QRS complexes. No equations are required in your answer to this question.

Draw a schematic sketch of a noisy ECG signal including three cardiac cycles with high-frequency and low-frequency noise, and illustrate how it is modified by each step.

Explain how the result could be used to measure the heart rate of a patient.

(10 marks)

Question 6: In the optimization procedure for the derivation of the Wiener filter, the coefficients of the filter are expressed as the vector $\mathbf{w} = [w_0, w_1, w_2, \ldots, w_{M-1}]^T$, where M is the order of the filter and T indicates the transpose. The current input sample $x(n)$ and $M - 1$ previous input samples are expressed in another vector as $\mathbf{x}(n) = [x(n), x(n - 1), \ldots, x(n - M + 1)]^T$.

(a) Write the full expression of convolution to define the output of the filter in terms of the input signal and the impulse response of the filter. Write the equivalent expression using the vectors as defined above and explain how the two methods lead to the same result.

(b) Explain the difference between $\mathbf{x}(n)\,\mathbf{x}^T(n)$ and $\mathbf{x}^T(n)\,\mathbf{x}(n)$.

(c) What does $E[\mathbf{x}(n)\,\mathbf{x}^T(n)]$ represent? Write a mathematical expression to give the detailed relationship between an element in the result and the input sample values.

(8 marks)

Question 7: A researcher wishes to use the electromyogram (EMG) to derive measures related to the force developed by muscle contraction. The researcher intends to record several segments of the surface EMG at various levels of contraction of a muscle of interest. Assist the researcher with the following:

(a) Explain how the surface EMG is related to the phenomena of spatial and temporal recruitment of the motor units in a muscle.

(b) Explain how the following may be computed from a segment of an EMG:

1. the root-mean-squared (RMS) value;

2. the turns count; and

3. the form factor (FF).

Give equations to define the RMS and FF values.

(c) Draw a schematic plot indicating the expected relationship between the RMS, turns count, and FF measures with increasing levels of muscular contraction. Explain and give reasons for your answer.

(d) Provide advice to the researcher on the various types of instrumentation, ambient, and physiological artifacts that could affect the EMG signal and the measures derived as above. Indicate how undesired artifacts and effects may be minimized or prevented in the proposed experiment.

(12 marks)

******