Carleton University, Systems and Computer Engineering

BIOM 5100/SYSC 5302: Final Exam: December 10, 2007

Instructor: *Andy Adler*

Instructions:

- This exam has **3** pages and **3** questions. Answer any **two (2)** of them. Marks are indicated

- You have **180 minutes** to complete this exam.

- This is a closed book exam; however, you are permitted to bring one (1) 8.5" $\times$ 11" sheet of notes into the exam. You are permitted to use a non-programmable calculator. You may not communicate with anyone during the exam except the instructor.

- Write your answers on an examination booklet. *You may take this examination paper with you*

Background: You are offered a job designing equipment to measure stress levels in subjects. As part of the interview, you are asked to design the following systems. However, after the interview, you personally research more on the company and their clients, and begin to suspect that the stress measurement equipment is used in interrogation of "high value" suspects. If this were an ethics exam (which it isn't) you would be asked to discuss the issues involved in this application of biomedical engineering. However, if you have time to consider the ethics, please refer to the last (bonus) question.

You may use the following equations and constants:

$E = mc^2$	$R_c = (8\eta L)/(\pi r^4)$	$E = E_0 + \frac{RT}{nF} \ln a_c$	Electron Charge: 1.6×10^{-19} Coul
$c = 3 \times 10^8 \frac{m}{s}$	$L_c = (\rho L)/(\pi r^2)$	$R = 8.31 \frac{J}{K \cdot mol}$	Atmospheric Pressure: 101.3 kPa
$F = ma$	$C = (\Delta Coul)/(\Delta V)$	$F = 9.65 \times 10^4 \frac{Coul}{mol}$	1 mol = 6.02×10^{23} particles
$V = IR$	$P(\frac{V}{N})^\alpha = Const$	$dV + \frac{V}{\alpha P} dP = \frac{1}{\rho} dN$	Blood Resistivity: $\rho_b = 450\Omega$·cm
$\rho_{air} = 1.21 \frac{kg}{m^3}$	$\rho_{blood} = 1060 \frac{kg}{m^3}$	$\eta_{air} = 1.8 \times 10^{-6}$ Pa $\cdot\, s$	$\eta_{blood} \approx 3.0 \times 10^{-3}$ Pa $\cdot\, s$

1. **EEG Measurement**

   The EEG signal reflects brain activity and changes with activity level. Several authors have claimed that there are features in the EEG that are associated with stress and specifically with truth telling, although this is somewhat controversial.

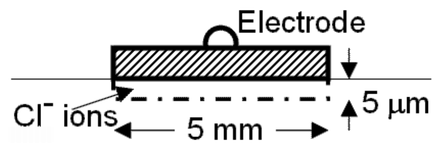
   (a) (5 points) The EEG signal originates in the electrical signals in the nerves in the brain. **Sketch a nerve axon. Briefly (≤ 50 words) describe how the electrical signal is generated. Show the movement of ions during the action potential.**

   (b) (5 points) Nerve axon potentials are rapid signals, with frequency content above 1 kHz; however, the frequency content of EEG resting rhythms are fairly low (1–6 Hz). **Briefly (≤ 50 words) describe why.** Consider the coordination of brain neurons and the "volume conductor" effect.

   (c) (5 points) Because the scalp is an insulator, the EEG signal levels are small, and high amplification is required. Consider an EEG signal which causes a difference of 15 μV between two electrodes. The neon interrogation lights cause a common mode signal of 1.8 V on the scalp. **Given an instrumentation amplifier with gain 10^5 and CMRR=80 dB, what level of common mode and difference signal will be measured? Will twisting the EEG lead wires together help to reduce the interference from the lights?**

(d) (5 points) **Show a driven right leg circuit and discuss how it helps improve issues with common mode signals.**

(e) (10 points) Based on the Nernst equation, we wish to estimate the capacitance in the equivalent circuit model for a platinum electrode. Charges in the electrode flow as electrons (e^-) and in the body as Cl^- ions, where $[Cl^-] = 0.15\frac{mol}{L}$ at body temperature (37 °C). **Estimate the capacitance of this electrode**. Consider a small ($\approx 10^{-6}\frac{mol}{L}$) change in $[Cl^-]$ under the electrode.



$[Cl^-]$ change is in a cylinder of 5 mm diameter and 0.5 μm depth under the electrode.

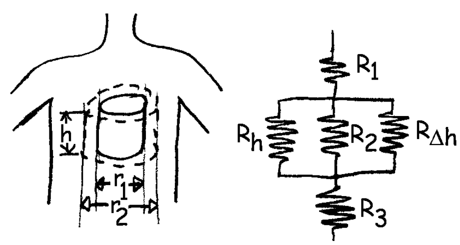
2. **Blood Flow Measurement.**

One key component of stress is changes in blood flow to the skin. This serves to allow increased cooling and is adaptive in a fight-or-flight scenario.

(a) (5 points) **Describe ($\leq$ 50 words) the principles used by infrared thermography to measure skin temperature.** Thermography is more reliable as a measure of temperature changes in a single subject than of temperature screening across a group of subjects. **Why?**

(b) (5 points) Ultrasound may be used to measure blood flow velocity, using the Doppler effect. **Sketch and describe ($\leq$ 50 words) an ultrasound flow measurement system**. Describe either a pulsed or continuous wave Doppler ultrasound system.

(c) (10 points) A 4-electrode impedance cardiography system is used to measure cardiac blood flow, with electrodes placed on the neck and waist. Assume the heart is cylindrical and composed only of blood, where $\rho_{blood} = 450\Omega\cdot$cm. The heart has radius r_1 at systole (and an equivalent resistance R_h), and radius r_2 at diastole. $R_{\Delta h}$ represents the change of resistance of the heart due to the ejected blood, **If the system resistance varies between a maximum of 486.4Ω and a minimum of 484.5Ω, what is the systolic ejection volume?**



Model of the resistivity of the thorax: $R_1 = 300\Omega$, $R_2 = 100\Omega$, $R_3 = 150\Omega$.

(d) (5 points) **Discuss two design issues ($\leq$ 30 words each) related to electrical safely in the impedance cardiography system**.

(e) (5 points) **Estimate the reduction in systolic pressure from heart to wrist**, assuming the artery length is 1 m, the inner diameter is 2 mm, and blood flows at $1\frac{mL}{s}$.

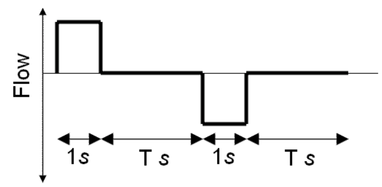
3. **Breathing Measures**

Breathing frequency (f_b), tidal volume (V_T), and functional residual capacity (FRC) change with stress level. Increases in each parameter provide greater oxygenation to tissue.

(a) (5 points) A very simple breathing measurement system uses a thermistor placed on the nose. In the simplest design, the thermistor is heated with a constant current, and the resistance is measured. Assume resistance is linear with $-T$ in the temperature range of interest. **Sketch a graph of the thermistor resistance, R_T and lung volume, V_L, in two scenarios:** i) **low f_b, V_T and FRC, and** ii) **high f_b, V_T and FRC.** Take into account the fact that thermistors have relatively slow time constants. **Which parameters (of f_b, V_T and FRC) can be measured with a thermistor?**

(b) (5 points) While a single thermistor cannot measure flow direction, flow direction can be measured with two thermistors. **Design and sketch a flow direction system based on two thermistors. Sketch the signals. Briefly discuss (≤ 30 words) a limitations of the design.**

(c) (10 points) Thermistors typically respond slowly. Consider a thermistor with time constant $\tau = 4.0$ s, and the subject to be breathing as shown at right. **Sketch the resistance at a breathing frequency, $f_b = 6$ min^{-1}. At what f_b is the output signal swing half of its value at $f_b = 6$ min^{-1}?** *Hint:* you may just consider the first two breaths starting at room temperature rather than finding the steady state.



Subject breathing with $f_b = (\frac{1}{2})\frac{1}{1+T}$.

(d) (5 points) One way to measure changes in FRC is to place the subject into a head-out body box. **Sketch a graph of the box pressure, P_b, and lung volume, V_T, in two scenarios:** i) **low f_b, V_T and FRC, and** ii) **high f_b, V_T and FRC. Which parameters (of f_b, V_T and FRC) can be measured with body box?**

(e) (5 points) Assume the head-out body box has a volume (not including the subject) of 100 L (containing room temperature air, 18 °C at atmospheric pressure). **What is the change in pressure for a 500 mL increase in tidal volume?**

4. **Ethics of the "Stress Measurement" Application** (Bonus question - 5 marks)

The application of medical instrumentation considered in this exam (interrogation) is clearly not for health care purposes. **Is this ethical? Discuss.**