BIOM 5100: Final Exam, December 14, 2009
Systems and Computer Engineering

Instructions:
- This exam has **3** pages and **16** questions for a total of 100 points. Answer 70 points worth of questions. (Thus, you may leave up to 4×5 point questions or up to 2×10 point questions)
- You have 3 **hours** $= 180$ **minutes** to complete this exam.
- This is a closed book exam; however, you may bring one 8.5" $\times$ 14" sheet of notes.
- You are permitted to use a non-programmable calculator.
- Write your answers on an examination booklet. You may take this paper with you.

Background: Stress affects a body in many significant ways. It has short term consequences of high blood pressure, increased and altered patterns of blood flow, and physiologicical alignment of the organism toward a "fight-or-flight" response. Stress has many signficiant long term consequences for health, too. Recently, it has become clear that many of the serious consequences of conducted energy weapons (such as the Taser) are due to the interaction of the electrical stimulation and the underlying stress in the subject. Since I've been thinking about this, I've made it the theme for this exam.

In this exam, we wish to develop instruments to monitor stress in order to conduct experiments of its effects. The classic biological indicators of stress are biochemical, such increased blood cortisol levels. However, since continuous measurement of blood chemistry is invasive, we consider several medical instruments to make measurements of stress in subjects:

1. (5 points) A conducted energy weapon (such as the Taser) works by causing muscular incapacitation, using a current that exceeds the *let go current* threshold. **Sketch current pathways**, if the subject is hit with one wire in the chest and one in the abdomen. Tasers work less well on large, obese subjects. **Explain (*briefly,* ≤ 50 *words*) why?**

2. (5 points) Photoplethysmography (PPG) is able to measure the pulsatility of blood flow to a finger or ear lobe. Stress decreases blood flow to peripheral arteries, and thus decreases the PPG signal. **Sketch the PPG signal before and after a stress event (such as a cut). Describe (*briefly,* ≤ 50 *words*) how PPT works. Why does it measure only *pulsatility* of blood flow and not *flow* itself?**

3. (5 points) A pulse oxymeter needs to be shielded from ambient light, so that the light detecting elements (photodetectors) receive only the signal from the pulsed red and infrared transmitters and not room light. **Sketch a pulse oxymeter and any transmitting and receiving components. Describe (*briefly,* ≤ 50 *words*) what measurements are made, and how ambient light causes signal distortions.**

4. (10 points) In class we described a pulse oxymeter using the equation $s_\lambda = k_g(a_{\lambda,\mathrm{Hb}} f_{\mathrm{Hb}} + a_{\lambda,\mathrm{HbO_2}} f_{\mathrm{HbO_2}})$ for the (processed) signal s_λ at wavelength λ. Consider a patient with $\mathrm{SaO_2} = 0.85$. Assume $k_g = 10.0$ (arbitrary units), and $f_{\mathrm{HbO_2}} = 1 - f_{\mathrm{Hb}} = 0.85$ (ie. No other species of Hb (such as HbCO) are present.)

   Values of a_λ (L/mmol/cm)

Wavelength	800 nm	660nm
Hb	0.20	0.81
$\mathrm{HbO_2}$	0.20	0.08
HbCO	0.01	0.06

   A: Calculate the signals, s_λ, for red and infrared light. Show how to calculate $f_{\mathrm{HbO_2}}$ from the pulse oxymeter signals.
   B: Because of inadequate sheilding, ambient light affects our pulse oxymeter. It increases s_{800} by 0.5 and s_{660} by 0.2. **What will the be the new estimate of $f_{\mathrm{HbO_2}}$ given this extra light?**

5. (5 points) The evoked potential signal in the EEG may show some changes with stress. **Describe an instrument (using block diagrams) to measure the auditory evoked potential (AEP) EEG.**

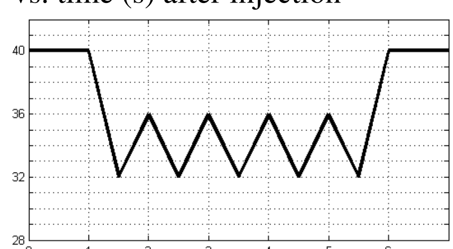
6. (5 points) The evoked potential signals are small compared to the overall EEG signal. One common approach to manage this problem is to use ensemble averaging. **Describe (*briefly,* ≤ 50 *words*) why evoked potential EEG signals are small and sketch a block diagram of ensemble averaging, based on the EEG and audio signal.**

7. (5 points) EEG signals are subject to movement artefacts if the electrodes move on the head during measurement. **A: Describe (*briefly,* ≤ 50 *words*) the origin of movement artefacts using a sketch of the ion concentration. B: Can movement artefacts be separated from the EEG using a frequency selective filter?** (ie. are movement artefacts in the same frequency range as EEG signals?)

8. (5 points) Cardiac output (CO) changes significantly in response to stress. The "gold standard" technique to measure CO is thermodilution. **Sketch a diagram of a thermodilution system showing the heart, any relevant blood vessels and desribe (*briefly,* ≤ 50 *words*) any measurements that are required.**

9. (10 points) 50 ml of cooled saline (4°C) saline is slowly injected (over 5 s) into right atrium and the temperature in a pulmonary artery measured (graph at right). The density (in $\frac{\mathrm{kg}}{\mathrm{L}}$) and specific heat (in $\frac{\mathrm{J}}{\mathrm{kg\cdot K}}$) of blood ($b$) and saline ($s$) are: $\rho_b = 1.06$, $\rho_s = 1.00$, $c_b = 3594$ and $c_s = 4139$. **Calculate the cardiac output.** Note, our patient has a slight fever, and so has elevated body temperature. Temperature oscillations are due to the beating heart.

   $\mathrm{T_{blood}}$ (°C) in pulmonary artery vs. time (s) after injection

10. (5 points) In the previous question, the temperature was measured using a fast thermocouple. If, instead we use a thermistor with a time constant $\tau = 5.0s$. **Sketch (roughly) the temperature output for this case.** Assume the thermistor is linear with temperature in this range. **How will this change affect the CO calculation (increase, decrease, same)? Why?**

11. (5 points) **What kind of shock hazzard (microshock, macroshock) does such a thermistor represent?** If there is a leakage current of 10μA flowing between the thermistor and the driven right leg circuit of an ECG amplifier, **sketch possible current pathways and describe (*briefly,* ≤ 50 *words*) how this may present a risk.**

12. (5 points) For indicator based measurements of blood flow, we need to account for possible *recirculation*. **What is recirculation? Compare the expected amount of recirculation from thermodilution with that from an indicator dye such as cardiogreen.**

13. (10 points) Stress affects the rate at which a subject consumes oxygen, which is measured by $\dot{V}_{\mathrm{O}_2}$. One strategy to measure oxygen consumption is a direct calorimeter, in which the subject is placed into a box (completely); air is pumped in, and the gas concentration and temperature of the output air is measured. We place our subject in a box of with a volume of 500 L (not including the subject). Assume the subject has $\dot{V}_{\mathrm{O}_2} = 250$ ml/min, and we wait long enough for the system to come to equilibrium (assume all processes are isothermal). Humidified atmospheric air at body temperature (37 ^{o}C) with a concentraion of 20% O_2 74% N_2 and 6% H_2O is pumped into the box at 10 L/min. Assume air is leaving the box at body temperature at the same rate. **What is the concentration of $\mathbf{O_2}$ in gas leaving the box?**

14. (5 points) Breathing efforts and breathing patterns are an important indicator of stress levels. The most common technique to measure the muscular efforts for breathing is with an esophageal pressure ($\mathrm{P_{es}}$) catheter. **Sketch the diagram of the lungs and chest showing a $\mathrm{P_{es}}$ catheter. Describe how this allows an estimate of pressure from breathing muscles.**

15. (5 points) **Sketch** $\mathrm{P_{mus}}$**, lung flow and volume** as a subject breathes in at 500 ml/s from FRC (functional residual capacity) to TLC (total lung capacity). IC (inspiratory capacity) is 3 L. Lung properties are $R_L = 1.6\frac{\mathrm{kPa}}{\mathrm{L/s}}$ and $C_L = 1.0\frac{\mathrm{L}}{\mathrm{kPa}}$.

16. (10 points) The $\mathrm{P_{es}}$ catheter is 2 m long with internal diameter 2 mm. It has a baloon of volume 10 ml and is connected to a pressure transducer with an internal volume of 5 ml. **Estimate the natural frequency and damping const of system. Can this system accurately measure normal breathing frequencies?** Properties of air: viscosity $\eta = 1.8 \times 10^{-5}$ Pa $\cdot$ s, density $\rho = 1.2 \times 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{L}}$, pressure $\mathrm{P} = 101.3$ kPa. Assume isothermal conditions.