SYSC 4203: Final Exam, December 21, 2009
Systems and Computer Engineering
Exam Number: 1

Instructions:

- This exam has **2** pages and **16** questions. Answer 81 points worth of questions.
  (Thus, you may leave 2×5 point questions or 1×10 point question)
- You have $2\frac{1}{2}$ **hours** $= 150$ **minutes** to complete this exam.
- This is a closed book exam; however, you are permitted to 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 examination paper with you.

Background: One key difficulty in intensive care is pain management. Patients are bored by lying in a bed (wouldn’t you be?), with nothing to think of but how they feel. To help these patients, clinicians will typically increase the anesthetic dose. This has several disadvantages, decreasing recovery times and possibly dependence on anesthetics.

One fascinating idea, especially for children in intensive care, is to provide a way for patients to play video games. Early tests show that patients are happier with lower doses of pain medication, leading to improved outcomes. However, the challenge is to adapt the game controller to the specific patient. For example, a burn victim may not be able to use her hands.

For this exam, we will consider two design concepts for a controller system which can work for a large group of such patients: 1) control via the electrical signals from muscles, and 2) control via breathing efforts. In both cases, the idea is that playing the game will also help strengthen the patient by training muscles.

1. (1 point) Your exam is exam number **1**. Write down this number.
2. (5 points) For patient safety it is important to have *electrically isolated* instrumentation devices. **Describe (*briefly,* ≤ 50 *words*) the function of electrical isolation, and describe one technology to implement it.**
3. (5 points) **Explain (*briefly,* ≤ 50 *words*) what a *motor unit action potential* (MUAP) is?** How is a MUAP related to the *single fiber action potential* (SFAP)?
4. (5 points) **Why (*briefly,* ≤ 50 *words*) is the EMG a stochastic signal, if the MUAP has the same shape at each contraction?**
5. (5 points) **Sketch** a block diagram of an instrumentation amplifier to measure the EMG signal from the biceps (arm) muscle which uses a driven right leg circuit. **Describe (*briefly,* ≤ 50 *words*) how the driven right leg circuit affects the common mode output of an amplifier?**
6. (5 points) Electromagnetic signals from nearby lights and motors can cause powerline interference in the recorded signal. **How does improving CMRR reduce this interference (*briefly,* ≤ 50 *words*)** .
7. (5 points) Movement artefacts can result in *baseline wander* in the output signals. **Describe (*briefly,* ≤ 50 *words*) the origin of movement artefacts.** Use a sketch of the concentration of ions beneath the electrode.

8. (5 points) We make initial tests of our EMG amplifier, and discover that the signal has interference from power line noise (60 Hz) and basline wander. **Sketch an example of the shape of such a signal in the time domain and frequency domain.** (Label your axes)

9. (5 points) The first game system is a "Mario Brother's" type game (in which the game character has to jump over obstacles). The idea is to compare the EMG signal to a threshold level and to make the character jump when the level is crossed. **Using a sketch, discuss (*briefly,* ≤ 50 *words*) one kind (out of the many possibilities) of unreliable performance that may occur if the EMG signal has baseline wander.**

10. (5 points) Because of infection, our patient's lungs have become stiff. **Sketch the Pressure-Volume curves of the static lung mechanics.** Show how it changes for stiffer lungs. **Does FRC change? If so, how?**

11. (5 points) Our patient is receiving ventilatory assistance. Part of this system is a Fleisch-type pneumotach at the mouth. **Sketch such a pneumotach and describe how it measures flow.**

12. (10 points) The cross sectional area of the pneumotach is 20 cm^2. This is filled with close packed tubes of length 2.0 cm. **Calculate the tube diameter so that the flow resistance of the device is** $1.0\ \frac{\text{kPa}}{\text{L/s}}$. (The flow resistance of a tube is $(8\eta L)/(\pi r^4)$ where $\eta_{\text{air}} = 1.8 \times 10^{-5}$Pa·s)

13. (5 points) While our patient is playing the video game, **we wish to monitor her oxygen consumption. Calculate $\dot{V}_{O_2}$ if she breathes at $12\ \frac{\text{breaths}}{\text{min}}$ with a tidal volume of $600\ \frac{\text{ml}}{\text{breath}}$ of 100% humidity warm ($37\,°$C) air**. Inspired air (atmospheric) is 21% O_2, and expired air has 17% O_2.

14. (10 points) If we assume the patient is in equilibrium (which isn't really true in this case) then we can use the Fick technique to estimate cardiac output (CO) from samples of arterial and venous blood. **Describe (*briefly,* ≤ 50 *words*) the Fick technique, and estimate CO**, given $C_aO_2 = 0.20\ \frac{\text{ml O}_2}{\text{ml blood}}$ and $C_vO_2 = 0.14\ \frac{\text{ml O}_2}{\text{ml blood}}$.

15. (5 points) The next idea for control of the video game is to use breathing efforts to make the game character jump. To do this, we wish to estimate breathing muscle effort from the esophageal, pressure P_{es}. **Sketch an equivalent circuit diagram of flow in the respiratory system, including P_{mus}, R_L and C_L. Describe (*briefly,* ≤ 50 *words*) how we can measure P_{mus} from P_{es}.** Assume $P_{ao} = P_{bs} = 0$.

16. (10 points) Consider a pulse oxymeter placed on an ear lobe in transmission mode. The light passes through 5 mm of tissue consisting of tissue (3 mm), venous blood (1.5 mm) and arterial blood (0.5 mm). During systole, the thickness of arterial blood increases to 0.6 mm (and the other tissues stay constant. Using the following table for the attenuation (μ) of light through tissue, **calculate the fractional change in the red and infrared pulse oxymeter signal from diastole to systole ($s_{\text{systole}}/s_{\text{diastole}}$). Describe (*briefly,* ≤ 50 *words*) how such a small signal can be used to measure arterial blood alone**.

μ (cm^{-1})	Tissue	Blood (Venous)	Blood (Arterial)
Red (660 nm)	2.5	4.5	1.4
Infrared (800 nm)	1.5	4.3	4.3