 Name _____

Final Exam

December 10, 2007

Permitted: Calculator, textbooks, handouts, and notes
Not permitted: Electronic communication or data storage devices

1. Discuss the following aspects of electrical isolation of hospital patients:
   The risks posed by unisolated equipment
   Safety features in the hospital electrical system
   Safety features in medical instruments
Please write in complete sentences and include labeled figures where appropriate.
(12 points for content, 8 points for clarity of explanation)

2. (30 points) The development of powered prostheses provides a variety of applications for control systems in biomedical engineering. As good bioengineers, we want to design systems that are close to biological reality as well as being functional in the worst case scenario. For the elbow, this scenario occurs when the forearm is pointed straight up. Answer the following questions by modeling the upward-pointing forearm as an inverted pendulum.

a. Write the system of differential equations that describes the inverted forearm system, including an input term that describes the net torque applied by the biceps and triceps muscles. The output of this system is the angular position. Use the following values:

Quantity	Symbol	Formula or value
Angular position	θ	0° when straight down
Mass of forearm	m	.6 kg
Length of forearm	L	40 cm
Moment of inertia	I_{ARM}	$(mL^2)/3$
Grav. acceleration	g	10 m/s
Damping coefficient	β	.25 N-m-s/angle

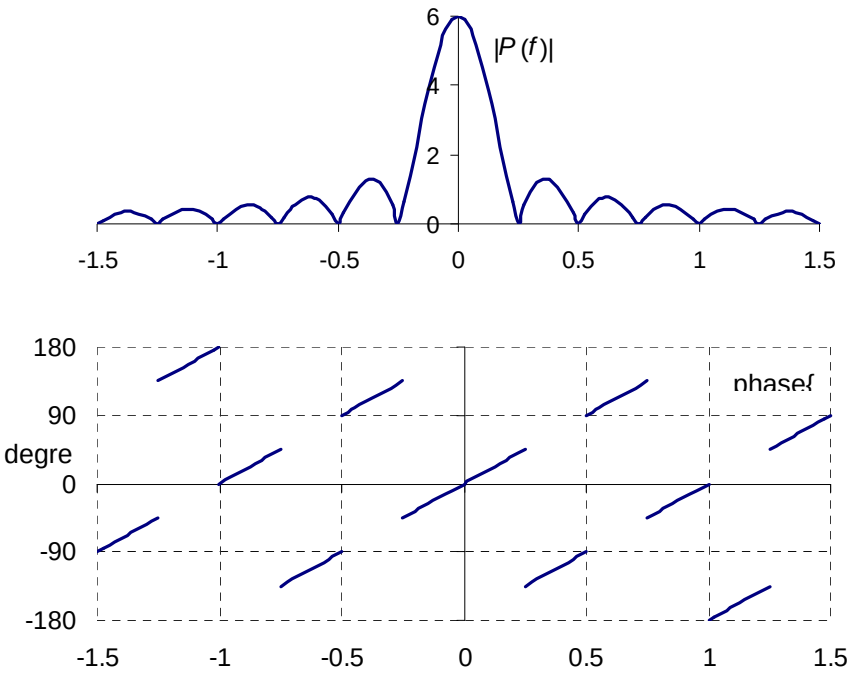
b. Identify the equilibrium points and linearize the forearm system about the non-trivial equilibrium point.

c. Describe the stability of this system and sketch its phase portrait.

d. Propose a controller for a biomimetic prosthesis that replaces the distal portion of the humerus, the elbow joint, and the forearm. The controller should maintain the forearm vertical over the elbow in response to a impulse disturbance.

- Briefly explain why this controller needs only two of the three PID gain components.
- Design the system to have a settling time of 1.25 second and to require no more than 75 N-m from the controller (ie net torque from the biceps and triceps) when the arm is held at 1 radian from the vertical (i.e., 180 +/- 60 degrees).

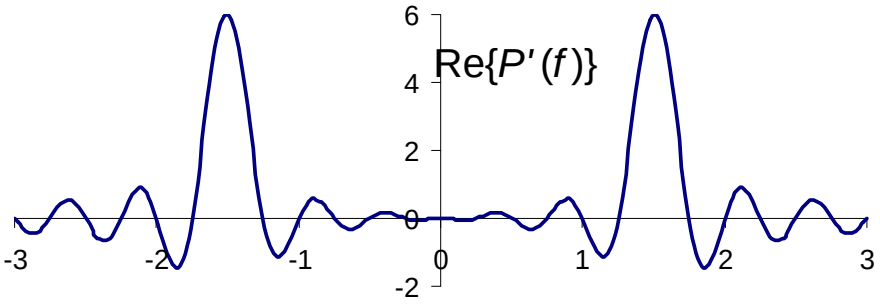
3. (25 points) The following figure is the frequency-domain representation $P(f)$ of a particular time-domain signal, $p(t)$. The horizontal axis is the frequency f in Hertz. $P(f)$ has the general form $\sin(x)/x$, with its first zero at ±0.25 Hz.



a) Describe two features in the figure (other than the label $|P(f)|$) that indicate that the upper plot is the magnitude of a Fourier transform, and not an intensity plot. (4 points)

b) Find and sketch the time-domain function $p(t)$, including numerical values where appropriate. (8 points)

3 (continued). The frequency-domain function has been modified as shown below, such that there are peaks at ±1.5 Hz. Note that this is now the real part of $P'(f)$; the imaginary part of $P'(f)$ is zero for all f.



c) Find the time-domain function $p'(t)$. (8 points)

d) In part (c) you should have found that $p'(t)$ is the combination of two simpler signals. Assuming that each simple signal is produced by a function generator, propose a circuit that could be used to combine the two signals. (5 points)

4. (25 points) The eye is an optical system that takes in light from the visual field and creates an inverted image on the retina. From the retina, the image detected by the rods and cones in the retina and transmitted via the optic nerve to the visual cortex in the brain. Vision can be diminished at almost every step in the optical path, including the cornea, lens, vitreous humor, retina, and optic nerve. Each one of these is, therefore, a target for biomedical engineering.

(a) Using principles from Fourier optics, explain why it is reasonable to assume that visual acuity (optical resolution) would be decreased when the pupil contracts.

(b) In persons with conditions such as astigmatism, the visual acuity can actually improve when the pupil contracts in response to elevated light levels. Keeping in mind the aberrations inherent in spherical lenses, provide a possible explanation for this improvement.

4. (continued) Suppose that we would like to design a complete prosthetic eye, including a lens and a digital retina. For simplicity, it is desirable to use a lens with a fixed focal length. However, if we optimize the lens for objects that are very far away, then the image of a closer object will be formed behind the artificial retina.

(c) Explain what optical information a digital retina might collect if the image is focused (1) slightly behind the retina, and (2) far behind the retina.

(d) Describe the advantages and disadvantages, if any, of recording frequency-domain information, compared to collecting an image the way our eyes do normally.

(e) Describe the processing that might be necessary to convert the frequency-domain information into an image for transmission along the optic nerve. It is not necessary to describe the interface with the optic nerve.