UNIVERSITY OF CALIFORNIA

College of Engineering
Department of Electrical Engineering
and Computer Sciences

Professor Fearing

Spring 1998

EECS 192

FINAL EXAMINATION

Tuesday, 20 May 1998, 5:00-8:00 p.m.

Name: _____ ID#: _____

- Closed book, closed notes. Calculators allowed.
- There are 13 problems worth 100 points total. Please try to answer concisely.

Problem	Points	Your Score	Problem	Points	Your Score
1	12		8	5	
2	8		9	6	
3	12		10	6	
4	12		11	6	
5	8		12	5	
6	10		13	2	
7	8				
Total	70			30	

Problem 1 (12 points) What is Mechatronics Good For?

For each system below:

- Briefly explain how you could implement a mechatronic approach to solving the problem.
- List required sensors, actuators, and outline control, testing, planning, user interface and safety systems as appropriate.
- Discuss how a mechatronic approach to the system could increase performance, capacity, utility, reduce costs, etc. (Read prospectus carefully before you invest....)
- Also discuss possible disadvantages of the mechatronic approach.

Answer any 2 of the 4 parts.

A) Freeways are congested. New freeways cost gigabucks. Describe a mechatronic approach to reducing freeway congestion.

B) Building structural responses should be overdamped so that earthquakes and high winds do not cause excess vibration. Describe a mechatronic approach to building lighter buildings with greater volume and lower structural costs.

C) You need a cheap, compact, accurate accelerometer. (An accelerometer typically measures displacement of a proof mass to determine acceleration.) Describe a mechatronic approach using inexpensive MEMS components.

D) Pick your own application for a mechatronic approach to a problem or system.

Problem 2 (8 points)

Consider the NMOS motor drive shown below:

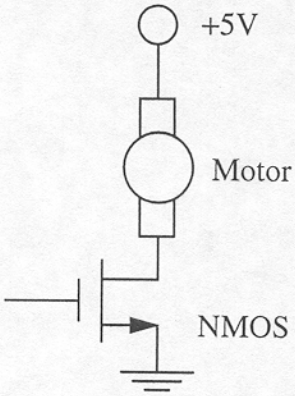


Figure 1

Typical Electrical Characteristics

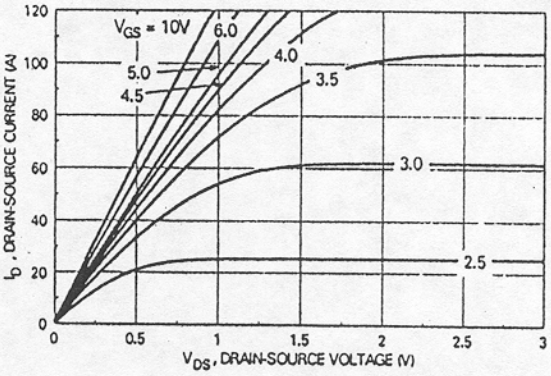


Figure 2: On-region Characteristics

The motor resistance is 0.1 ohm. Recall $P = I^2R$, $P = VI$. Assume the motor is stalled.

[4 pts.] **a)** Given that the NMOS transistor is able to dissipate 30 Watts, estimate the minimum V_{GS} required to prevent NMOS failure.

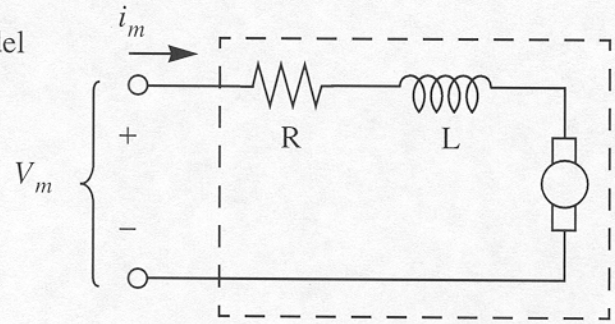
[4 pts.] **b)** What is the efficiency $\left(\frac{P_{\text{motor}}}{P_{\text{motor}} + P_{\text{transistor}}}\right)$ of the circuit when $V_{GS} = 5\text{V}$?

Problem 3 (12 points)

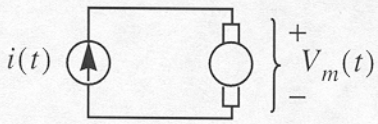
For this problem, consider a DC permanent magnet motor (as used in your car). The car is on a carpet and moves in a straight line with no slip between the wheels and the carpet. The car is initially moving at a speed of 2 meters per second.

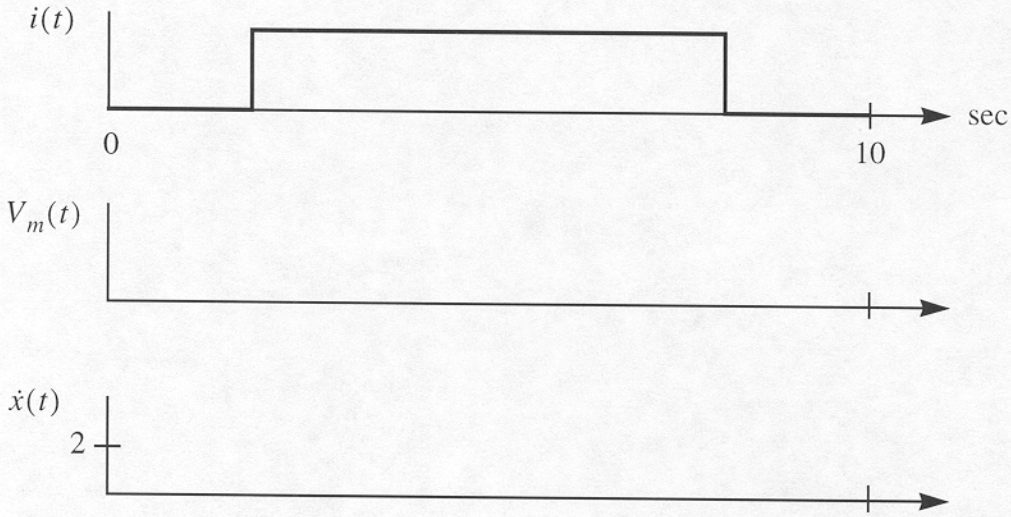
You can assume a motor model as shown below. The qualitative shape of the curves is more important than magnitudes.

motor model

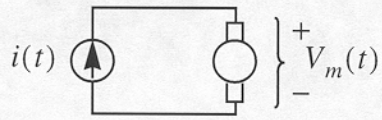


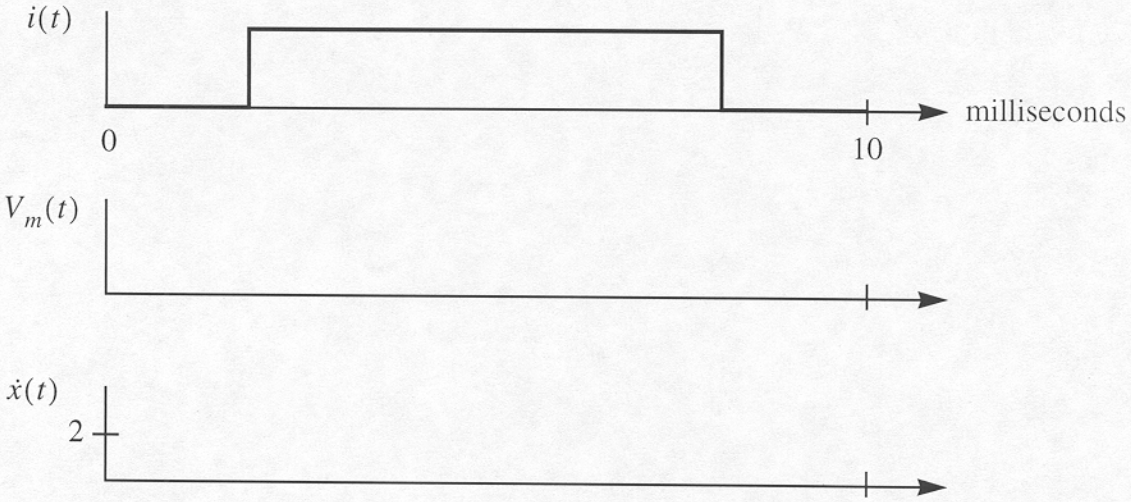
[3 pts.] **a)** Consider the motor driven from a current source with current $i(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal voltage for the time indicated.



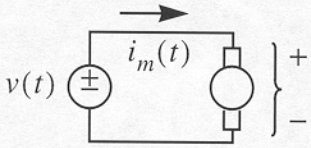


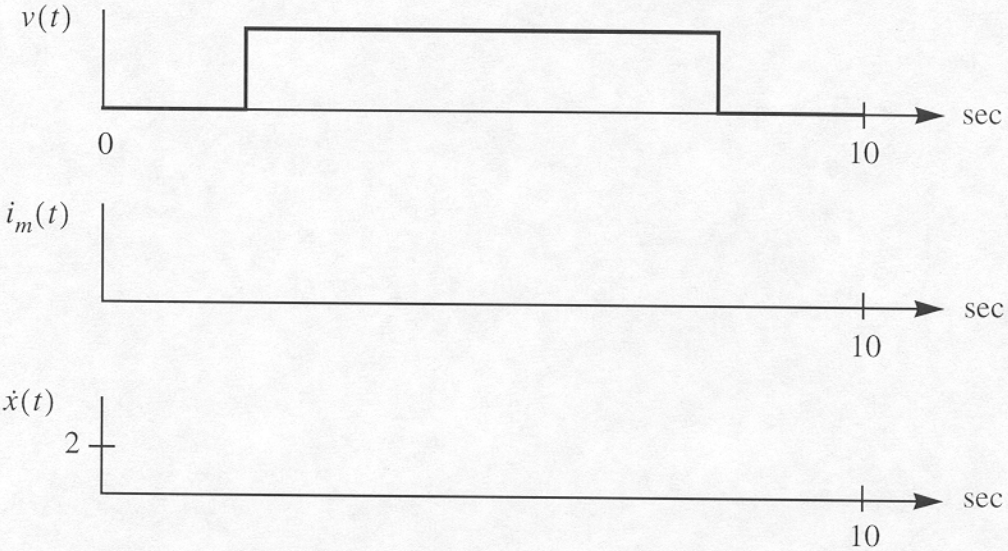
[3 pts.] **b)** Consider the motor driven from a current source with current $i(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal voltage for the time indicated.



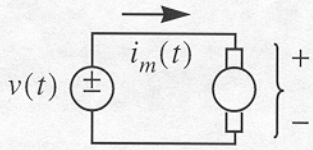


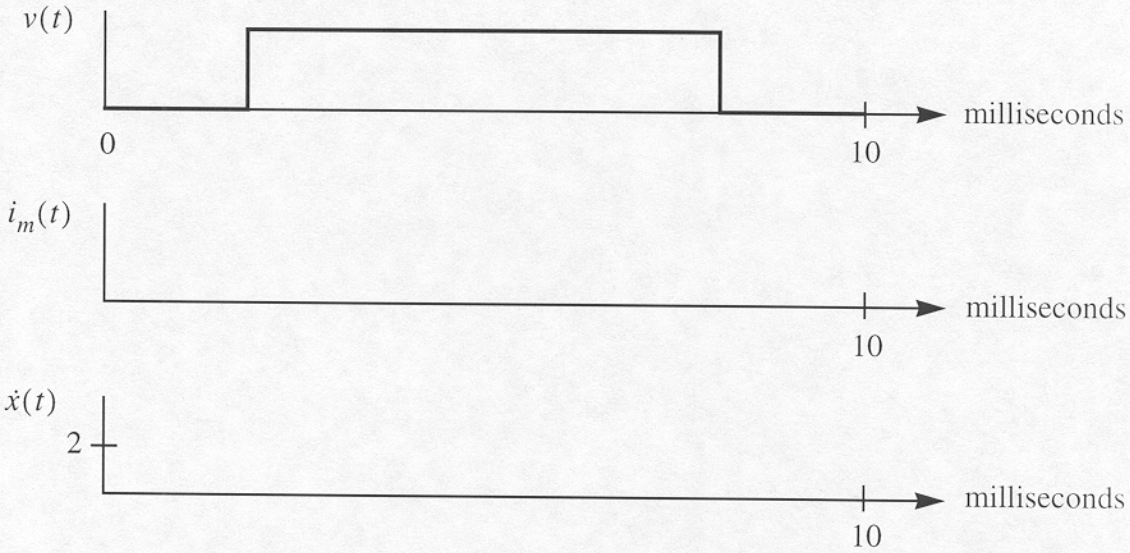
[3 pts.] **c)** Consider the motor driven from a voltage source with voltage $v(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal current for the time indicated.





[3 pts.] **d)** Consider the motor driven from a voltage source with voltage $v(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal current for the time indicated.





Problem 4 (12 points)

Your partner wrote the velocity code below, which runs in the real-time routine every 5 ms. Your wheel encoder returns the position of the wheel with 1 cm resolution.

```
int old_pos, new_pos, vel_est, u;
int vel_des; /* desired velocity, set by top level of program */
int vel_err; /* error between measured and sensed velocity */
velocity_control{}
{new_pos=read_wheel (); /* read wheel position */
vel_est  =  (new_pos – old-pos);
old_pos =  new_pos;
vel_err  =  vel_des – vel_est;
u = u + v_err;
if ( u < 0 ) u = 0;
PWMREG = u;          /* write new PWM value to xilinx register */
}
```

[4 pts.] **a)** You want to explain this code to a colleague. Draw a system diagram (showing feedback loop) which shows the control action being used.

[4 pts.] **b)** This velocity controller doesn't do a very good job of maintaining car speed. Explain in as much detail as necessary, why this algorithm does not work as desired.

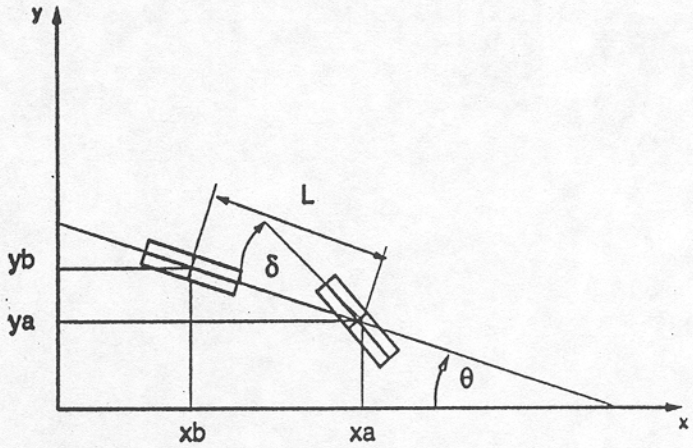
[4 pts.] **c)** Suggest fix(es) which would probably improve the velocity controller's performance.

Problem 5 8 points)

Consider the vehicle steering model shown below:

Table 1: Definition of Variables

Variable	Description
x_b	X coordinate of midpoint of rear axle
x_a	X coordinate of midpoint of front axle
y_b	lateral displacement w.r.t. road centerline at rear axle
y_a	lateral displacement w.r.t. road centerline at rear axle
δ	steering angle
L	wheel base
θ	relative yaw angle w.r.t. road centerline
V	vehicle speed



Bicycle Model for Steering Kinematics

The kinematic equations are given by:

$$\dot{x}_b = V\cos(\theta(t)) \tag{1}$$

$$\dot{y}_b = -V\sin(\theta(t)) \tag{2}$$

$$\dot{\theta} = \frac{V}{L}\tan(\delta(t)) \tag{3}$$

$$y_a = y_b - L\sin(\theta(t)) \tag{4}$$

[4 pts.] **a)** Derive the linearized differential equation relating steering angle δ to lateral displacement y_a.

[4 pts.] **b)** Explain, based on the differential equation for steering given above, why you could expect oscillatory behavior using proportional control.

Problem 6 (10 points)

A system is described by the linear differential equation:

$$\dot{x} = ax + bu$$

where a and b are positive constants, and u is the control input.

[3 pts.] **a)** Draw a block diagram for a proportional controller with gain k which will cause state x to asymptotically approach some command $r(t)$.

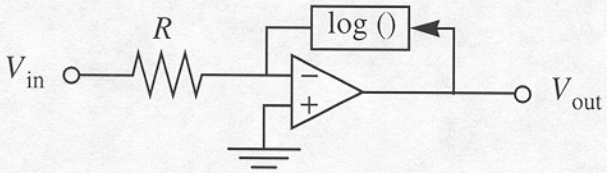
[2 pts.] **b)** For what range of k is this controller stable?

[2 pts.] **c)** If the continuous controller is replaced by a discrete time controller, qualitatively explain why or why not the range of k for stable operation changes.

[3 pts.] **d)** Does a discrete time control function need to run on a system with guaranteed maximum response delay (a real time system)? Explain why or why not.

Problem 7 (8 points)

Consider the ideal op am circuit below which calculates $v_{out} = f(V_{in})$.



[4 pts.] **a)** What function is calculated?

V_{out} = _____

[4 pts.] **b)** What important principle is being applied in this circuit? Explain how the same general principle is used in the steering control system.

Problem 8 (5 points)

Control theory is quite complete and one can easily prove stability and performance properties for linear systems with linear controllers such as proportional plus derivative (PD). When we apply proportional plus derivative control to the steering control system on the car, the linear system model is only an approximation. List 5 practical reasons, e.g., specific component limitations, why this approximation may not be appropriate in all circumstances for steering control.

1.

2.

3.

4.

5.

Problem 9 (6 points)

What is meant when we say we have background and foreground processes in a real time control system? What are some of the advantages and disadvantages of this approach?

Problem 10 (6 points) Velocity Sensing

You are given the task of designing an optical sensing system (wheel mounted) to measure car velocity.

List 3 different combinations of sensor devices, hardware, and software which could be used to give a reasonable estimate of velocity for speed control.

1.

2.

3.

Problem 11 (6 points)

How can lookup tables be used to improve sensor, actuator, or control system performance? List 3 places they might be useful.

1.

2.

3.

Problem 12 (5 points)

Your company is building a mechatronic product. Your manager hasn't taken EE192. Your manager is ready to ship the product, and to save money, circuit boards are held by two screws at one end. How could you convince your manager that this is going to be costly?