MSE 480/780 – Final Exam

Sunday, April 22nd, 12:00pm, Room 2600*

*** Room & seating assignments provided**

Exam Rules

Non-programmable calculators may be used. With the instructor's permission, specific programmable calculators may be used provided that all memory is cleared before the exam begins and any communication capabilities are disabled.

No smartphones, smart watches or other electronic devices may be used.

Two pages (8.5" x 11", both sides) of handwritten notes are permitted.
Spot checks may be carried out during the exam to ensure notes pages are individually prepared and handwritten.

All writing must stop at or before 3:00pm and exam booklets handed in

Students must seat themselves according to the seating assignment provided
Exceptions will be handled by the course instructor as needed

As per SFU Final Exam Policies:

SFU ID cards must be made available and students must sign the attendance sheet provided

Students will not be permitted to enter the exam after the first 30 minutes, or leave within the first 30 minutes

Students should not leave during the final 15 minutes (i.e. should remain seated)

Only one student at a time will be permitted to leave the room to use the washroom

Total Marks: 100

IDENTIFY ALL FINAL ANSWERS CLEARLY AND UNAMBIGUOUSLY

*This exam has **5** pages*

Problem 1 (25 Marks)

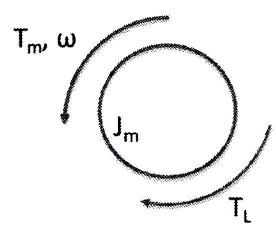
A standard DC servomotor is used to control the drive screw that compresses a polymer (the raw material) in an extrusion process. The motor has the following specifications:

- Torque constant, K_t = 0.225 N-m/A
- Voltage constant, K_v = 0.108 V/(rad/sec)
- Armature resistance, R_a = 2.5 ohms
- Rotary interia, J_m = 3.25*10^{-3} kg*m^2

Because the polymer's resistance to flow is nonlinear, the load torque on the motor as a function of speed (at the operating temperature of the process) is also nonlinear and can be approximated as:

$$T_L = K_{L1}\omega + K_{L2}|\omega|\omega$$

where T_L = load torque at the motor's output shaft, N-m; ω = angular velocity, rad/sec; K_{L1} = 0.05 N-m/(rad/sec), and K_{L2} = 0.0024 N-m/(rad/sec)^2. Considering the motor as a rotary inertia, the schematic figure below shows the positive directions for ω, T_L and the motor torque T_m.



A specific amplifier is used to control *current* in the motor's armature (instead of applying a fixed voltage). If the amplifier is used to produce an instantaeneus and constant current of +10A in the motor's armature, and the motor is initially *at rest*:

a. What is the voltage at the motor's input the instant before it starts turning?

b. What is the steady-state speed of the motor, in RPM?

c. What torque (in N-m) is being produced by the motor at the steady-state speed?

d. What is the voltage at the motor's input at the steady-state speed?

e. What power (in Watts) is being generated by the motor at the steady-state speed?

Problem 2 (25 Marks)

A specific 6 DOF industrial robotic system is made up of a 3 DOF manipulator (with joint variables θ_1, d_2, d_3) and a spherical wrist (with joint variables θ_4, θ_5, θ_6). Following are the homogeneous transformations $A_{01}(\theta_1)$, $A_{12}(d_2)$ and $A_{23}(d_3)$ for the 3DOF manipulator, and $A_{3t}(\theta_4, \theta_5, \theta_6)$ for the spherical wrist. Note that the origin of frame F_3 is at the "wrist centre" of the spherical wrist, and the tool frame transformation A_{6t} is equal to the identity matrix.

0.7071

$$A_{01} = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad A_{12} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad A_{23} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_{3t} = A_{36} = \begin{bmatrix} c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6 & -c\theta_4 c\theta_5 s\theta_6 - s\theta_4 c\theta_6 & c\theta_4 s\theta_5 & c\theta_4 s\theta_5 \\ s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6 & -s\theta_4 c\theta_5 s\theta_6 + c\theta_4 c\theta_6 & s\theta_4 s\theta_5 & s\theta_4 s\theta_5 \\ -s\theta_5 c\theta_6 & s\theta_5 s\theta_6 & c\theta_5 & c\theta_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The following homogeneous transformation T_{0t} represents the desired position and orientation of the system's end effector:

$$T_{0t} = \begin{array}{c} \begin{bmatrix} 0 & 0 & 1 & 1.3536 \\ 0 & -1 & 0 & 0.3536 \\ 1 & 0 & 0 & 1.5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{l} x \\ y \\ z \\ \end{array}$$

Assume that the first three joint variables have *__already been solved and selected__* (to obtain the desired position of the wrist centre at $[1.3536\ 0.3536\ 1.5]^T - d_6 R_{0t}[0\ 0\ 1]^T$ where R_{0t} is the rotation matrix portion of T_{0t}, and d_6 is the distance from the wrist centre to the end effector) as:

$\theta_1 = \pi/4$, $\quad d_2 = 0.5$, $\quad d_3 = 0.5$

Using these values for θ_1, d_2 and d_3, **Determine the remaining three joint variables (θ_4, θ_5, θ_6) that will produce the desired orientation of the end effector**. You may assume that $\sin(\theta_5) > 0$.

In case it is useful as a reference, following is the solution for the "Euler ZYZ" rotation matrix parametrization:

Given

$$R_{zyz}(\varphi, \theta, \psi) = \begin{bmatrix} c\varphi c\theta c\psi - s\varphi s\psi & -c\varphi c\theta s\psi - s\varphi c\psi & c\varphi s\theta \\ s\varphi c\theta c\psi + c\varphi s\psi & -s\varphi c\theta s\psi + c\varphi c\psi & s\varphi s\theta \\ -s\theta c\psi & s\theta s\psi & c\theta \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x \\ n_y & s_y & a_y \\ n_z & s_z & a_z \end{bmatrix}$$

For $\sin(\theta) > 0$:

$$\varphi = atan2(a_y, a_x), \qquad \theta = atan2\left(\sqrt{a_x^2 + a_y^2}, a_z\right), \qquad \psi = atan2(s_z, -n_z)$$

Otherwise for $\sin(\theta) < 0$:

$$\varphi = atan2(-a_y, -a_x), \qquad \theta = atan2\left(-\sqrt{a_x^2 + a_y^2}, -a_z\right), \qquad \psi = atan2(-s_z, n_z)$$

Problem 3 (15 Marks)

The following truth table describes the behavior of a combinational logic circuit with one output (*f*) and four inputs (x_1, x_2, x_3, x_4).

a. Develop a minimum-cost sum-of-products (SOP) expression for the function $f(x_1, x_2, x_3, x_4)$.

b. Design (draw) a circuit that implements the function $f(x_1, x_2, x_3, x_4)$ using only AND, OR and NOT gates.

c. Convert the resulting network into a ladder logic diagram.

x_1	x_2	x_3	x_4	f
0	0	0	0	0
0	0	0	1	0
0	0	1	0	1
0	0	1	1	1
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	0

Problem 4 (35 Marks)

Part a (20 marks)

A worker is currently responsible for tending two machines in a machine cluster. Each machine required an initial investment of $155,000 with a 12-year service life and no projected salvage value. The company's rate of return is 17.5%, and the machine cluster operates for a single shift (2000 hrs/year).

The service time per machine (per cycle) is 0.75 min and the time to walk between machines is 0.20 min. The portion of the cycle time for which the machine operates automatically is 1.90 min. The factory's labour overhead rate is 26%, and the machine overhead rate is 22%. If the worker's hourly rate = $18/hr, determine:

- The current hourly rate for the cluster
- The current cost per unit of product, given that one unit is produced by each machine during each machine cycle and assuming raw material costs of $6.50 per unit.
- What is the percent idle time of the worker?
- What is the optimum number of machines that should be used in the machine cluster, if minimum cost per unit of product is the decision criterion and all other parameters remain unchanged?

Part b (15 marks)

The following table shows "From/To" sequencing data for a collection of machines that are to be arranged in a manufacturing cell.

- Determine (using Hollier Method 2, as described in the course notes and text) an appropriate arrangement for the machines within the cell
- Sketch the flow of parts (with corresponding quantities) and evaluate the performance of this arrangement with respect to in-sequence moves, by-passing moves and back-tracking moves.
- Would you make any specific recommendations regarding the layout of the cell?

	To				
From	1 (Grind)	2 (Mill)	3 (Annodize)	4 (Drill)	5 (Lathe)
1 (Grind)	0	0	70	0	0
2 (Mill)	0	0	30	130	0
3 (Annodize)	0	0	0	0	0
4 (Drill)	10	0	120	0	0
5 (Lathe)	90	10	0	0	0