MECH ENG 4H03 Practice Problem Set 1

NOTE: Please show your work and include all relevant equations.

1. An encoder is attached directly to the shaft of a motor. The maximum torque produced by the motor is 2 Nm. All other torques are negligible. The moment of inertia of the motor plus load varies from 2×10^{-3} kgm^2 to 5×10^{-2} kgm^2. The encoder produces 300 pulses per revolution. The controller estimates velocity by backward differencing position measurements taken every 0.005 s. The controller uses quadrature counting. Calculate the worst case velocity error.

2. A force sensor has a sensitivity of 20 mV/N, a range of ±400 N and an accuracy of ±0.25% of full scale.
   a) Assuming other sources of error in the measurement system are insignificant, what is the accuracy in units of the measured quantity?
   b) The sensor's output impedance is 1 kΩ. It is connected to an ADC with a 100 kΩ input impedance. Repeat part (a) including the effect of these impedances.
   c) The ADC has a 12-bit resolution with 11.2 effective bits. Its input range is ±10 V. Repeat part (b) including this source of error.
   d) If the input is 100 N, calculate the worst case measurement error. Is it ¼ of the worst case error you found in part (c)? Explain why or why not.

3. A pressure measurement system has a rise time of 1.5 ms, a range of 100 kPa to 500 kPa, and an accuracy of ±500 Pa.
   a) If its current output is 350 kPa, and a valve is opened causing the input pressure to suddenly increase, how long should the mechatronic system wait before taking its next reading?
   b) If the measurement is taken 3 ms after the input pressure increase, what is the worst case measurement error?
   c) Now the input pressure is fluctuating at 100 Hz with an amplitude of 5 kPa. Its mean value is 200 kPa. What is the worst case error in the pressure measurement?

4. You are given a temperature sensor but the value of its internal resistance R_s is unknown. The temperature of the sensor is held constant. You connect a 10,000Ω resister across the sensor terminals and the measured voltage is 5.0V. You then connect a 5,000Ω and the voltage drops to 4.95V.
   (a) Calculate the internal resistance of this sensor.
   (b) For the same temperature, what is the percentage error due to loading effects when R_{in}=20,000Ω?

5. Prove that T_{opt} from equation 2.38 minimizes Δv_{est} .
   Hint: You need to show that $\frac{\partial \Delta v_{est}}{\partial T}(T_{opt}) = 0$ and $\frac{\partial^2 \Delta v_{est}}{\partial T^2}(T_{opt}) > 0$.

6. The data listed in the table below was collected from a pressure sensor for the purposes of calibration. Note that the mean sensor output is given. The standard deviation of the sensor output was not affected by the pressure input, and equalled 0.05 V.

a) Fit a straight calibration line (by linear regression) of the form Y=AX to the sensor data using the equations from the notes.

b) Show one example of calculating the pressure output (i.e. the pressure indicated by the sensor). Next, create and fill in a table with the following columns: Test #, Pressure Input (kPa), Mean Output (V), Pressure Output (kPa), and Error Magnitude (kPa). Use all of the given data.

c) Determine values for the following performance specifications: i) accuracy, ii) sensitivity, iii) hysteresis, iv) linearity, v) repeatability and vi) dead band.

d) Repeat parts a), b) and c) (in their entirety) for a calibration line of the form Y=AX+B.

e) What is the advantage(s) and disadvantage(s) of using an AX+B fit rather than an AX fit?

Test #	Pressure Input (kPa)	Mean Output (V)
1	0	0
2	12.5	0.3
3	25	0.9
4	37.5	1.62
5	50	2.52
6	62.5	3.72
7	75	4.8
8	87.5	5.4
9	100	6
10	87.5	5.7
11	75	5.28
12	62.5	4.5
13	50	3.6
14	37.5	2.4
15	25	1.32
16	12.5	0.48
17	0	0

7. The step input response data for a temperature sensor is given in the table (continued on the next page). You may assume that the final value is 20°C. From this data, determine conservative values of:
a) Time constant, b) Rise time, and c) Settling time.

Time (ms)	Temp. Output (°C)
0	0
0.5	1.21
1.0	2.35
1.5	3.42
2.0	4.42
2.5	5.37
3.0	6.25
3.5	7.09
4.0	7.87
4.5	8.60
5.0	9.29
5.5	9.94
6.0	10.55
6.5	11.13
7.0	11.66
7.5	12.17
8.0	12.65
8.5	13.09
9.0	13.51
9.5	13.90
10.0	14.27
10.5	14.62
11.0	14.94
11.5	15.25
12.0	15.54
12.5	15.81
13.0	16.06
13.5	16.30
14.0	16.52
14.5	16.74
15.0	16.93
15.5	17.12
16.0	17.29
16.5	17.46
17.0	17.61
17.5	17.76
18.0	17.89
18.5	18.02
19.0	18.14
19.5	18.25
20.0	18.36
20.5	18.46
21.0	18.55

21.5	18.64
22.0	18.72
22.5	18.80
23.0	18.87
23.5	18.94
24.0	19.00
24.5	19.06
25.0	19.12
25.5	19.17
26.0	19.22
26.5	19.27
27.0	19.32
27.5	19.36
28.0	19.40
28.5	19.43
29.0	19.47
29.5	19.50
30.0	19.53
30.5	19.56
31.0	19.58
31.5	19.61
32.0	19.63
32.5	19.66
33.0	19.68
33.5	19.70
34.0	19.71
34.5	19.73
35.0	19.75
35.5	19.76
36.0	19.78
36.5	19.79
37.0	19.80
37.5	19.82
38.0	19.83
38.5	19.84
39.0	19.85
39.5	19.86
40.0	19.87

8. A temperature control system uses a proportional plus integral plus derivative (PID) feedback controller. The control system will estimate the derivative by computing the backward difference of the measured temperature. The temperature measurement has a repeatability of $\pm 0.5\ ^{\circ}C$. The maximum second derivative equals $0.1\ ^{\circ}C/s^2$. What sampling period should be used when calculating the derivative of the temperature? What is the worst case error of the estimated derivative when using this sampling period?

9. You must select a suitable sensor for measuring the liquid level in a large tank. The liquid has a density of 1100 kg/m^3. The tank is a cylinder with radius of 3 m and a height of 6 m; and is enclosed (not airtight) with slowly changing levels. The sensor must be capable of measuring the liquid level within ± 2 cm.

a) Which, if any, of the differential pressure sensors listed below is suitable?

Differential pressure sensor	Accuracy	Range
A	±200 Pa	5 kPa to 75 kPa
B	±200 Pa	0 kPa to 70 kPa
C	±250 Pa	0 kPa to 70 kPa

b) If the sensing system is built by using a force sensor mounted under the tank and the empty weight of the tank is 5000 kg, which, if any, of the sensors listed below satisfies the requirements?

Force sensor	Accuracy	Range
A	±6 kN	0 to 1.5×10^6 N
B	±7 kN	0 to 2×10^6 N
C	±6 kN	0 to 2×10^6 N

10. Based on the material covered in this course, answer the following questions:

a) List the two main types of force sensors.

b) What type of temperature sensor has the largest sensitivity?

c) List two disadvantages of sensing velocity by differentiating the displacement measurement.

d) List the two main methods for depth sensing (Hint: List methods not sensors).

e) List one advantage and one disadvantage of using a microswitch as a proximity sensor.

f) What advantage do strain gauge-based displacement sensors have over potentiometers?

g) For safety-critical applications, _____ control is always preferable to _____ control.

h) If they are required to have the same resolution, would an incremental optical encoder need to have a larger, smaller or equal diameter compared to an absolute optical encoder? Justify your answer.

i) What is the desirable bandwidth for an automobile gas tank liquid level sensor? Your choices are: small, medium or large. Justify your answer.

j) What six elements make up a typical closed-loop control system?

k) If the stiffness of a strain gauge-based force sensor is decreased then its _____ specification will worsen and its _____ specification will improve.

l) Give two reasons why computer simulations are very important in mechatronics engineering.

m) Define the sensor specification termed *hysteresis*.

n) A sensor manufacturer provides values for its rise time, settling time and time constant. Order them by their magnitudes from largest to smallest.

o) Draw a simple design for a strain gauge-based accelerometer. Label the strain gauge. Use an arrow to indicate the measurement direction.

p) A _____ is a simple, inexpensive sensor for measuring flow rate.

q) You are interfacing an analog sensor to a microcontroller. The sensor must be located 100 m from the microcontroller. Is it better to connect the longest cable between the sensor and the amplifier, between the amplifier and the low-pass filter, or between the A/D and the microcontroller? Rank these three choices from best to worst and explain your reasoning.

r) Other than a microswitch, list two types of proximity sensors.