CMPE 167: Sensors and Sensing

Homework 2

Question 1: Footprint Sensor Problem

It is Easter weekend and all electronics hardware stores in your town are closed for the holidays. However, a recent report on the increasing crime rate in your area had gotten on your nerves, and you've decided to do something about it right away. Digging out your toolkit from a sensor class that you had taken years ago, you find a lot of capacitive transducers that consist of a pair of electrodes separate by a compressible material layer. Your idea is to attach a few of these capacitive devices to a long metal strip under the mat right behind your apartment door where every entering person would surely step. You also plan to hook it up with some electronics and to a siren system that hopefully would scare any potential burglars away when anyone steps on it. For now, were just going to worry about the sensor. After running some simple experiments you figure out the following:

a) The capacitive sensor consists of a pair of circular electrodes, each with an area of 10cm x 10cm. The gap between the electrodes is 1 millimeters. Assume the compressible material layer has a relative permitivitty of 20. What is the capacitance?

b) You hook up the sensor in a simple low pass configuration. What is the amplitude of V_{out} if you use a 5V source at 1kHz as your V_{in} ? (Assume C is the capacitance from the first question and that R is 100kΩ)

c) Now, you tried to step on the mat with varying weight, and you determine that the gap, X, has a transfer function with the weight X(w) = 1mm-0.004w, where w is the weight in kilograms. What is the range of your new V_{out} if a 70kg guy steps on it and stands there?

d) You also figure out that a potential burglar would not stand still on your mat. Think about what the typical event would be like, and draw a picture of the signal at V_{out} as a function of time during a typical event.

Question 2: Strain Gauge Load Sensor

Your lab partner is setting up an apparatus to measure strains. He has a strain gauge with a gauge factor of 3 and a nominal (strain-free) resistance of 1000 Ohms. The strain gauge is mounted on the top of a rectangular aluminum bar with dimensions of 10 cm (long) x 2 cm thick x 4 cm wide. Your partner connects this strain gauge to a simple Wheatstone bridge consisting of 1000 ohm resistors. The bar is fixed at one end and free at the other. Loads are placed at the free end of the beam. (Please use a modulus of elasticity (E) of 73.1 GPa)

a) What is the resistance of the strain gauge when an added load of 1 kg is applied to the end of the beam?

b) The Wheatstone bridge is biased with a 5V Vin. What is the voltage difference between the sense and reference terminals of the bridge?

Question 3: Thermometer Noise Calculation

The LM35 thermometer data sheet (on CANVAS) Figure 10 shows the plot of the noise spectral density. Using an average over the frequencies of interest please answer the following questions:

a) If you connected the output of this sensor to a low pass filter with a cutoff at 100 Hz, and made sure that there were no temperature changes, what would the amplitude of the RMS noise be?

b) If the filter cutoff frequency were changed to 1Hz, what would the RMS noise amplitude be?

Question 4: Force Sensor + Circuit Calculations

A resistive contact force sensor has a response given by :

$$R = (1000\Omega)(1 + \frac{F}{200N})$$

This sensor is to be used for measuring forces ranging from 0 to 50N. Please design a measuring circuit that will produce an output voltage that ranges from 0V to 4V as the applied force ranges from 0 to 50N. Please design this circuit so that the nonlinearity in the relationship between force and voltage is less than 1% of the full scale output.

Question 5: Cantilever

A cantilever beam has a pair of strain gauges mounted on the top and bottom of the beam, so that bending of the beam causes one to increase in resistance and the other to decrease in resistance. In equation form, $R_1 = 1000\Omega(1 + \text{force}/1000N)$, and $R_2 = 1000\Omega(1 - \text{force}/1000N)$. These are wired together as a voltage divider with R_2 on top.

a) If the bias voltage is 5V, what is the output voltage as a function of load force?

b) Using the Taylor series expansion (as in other homework problems), estimate the size of the quadratic error term relative to the linear term.