National Exams   May 2018

04-Agric-A5, Principles of Instrumentation

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
    Any non-communicating calculator is permitted.

3. Questions 1, 2 and any other THREE (3) questions constitute a complete exam paper. Only questions 1, 2 and the first THREE (3) other questions as they appear in your answer book will be marked.

4. All questions are of equal value.

Question 1. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a) (2 marks)   Why is it incorrect to add standard deviation values together?

b) (2 marks)   What assumption must be made when a two point calibration is used?

c) (2 marks)   Why can the accuracy of a sensor not be determined by statistical methods?

d) (2 marks)   Why should calibration errors be plotted as a function of the standard values used?

e) (2 marks)   What is a 'blank' sample?

f) (2 marks)   How is an 'internal' standard used?

g) (2 marks)   What defines the lowest quantity that a sensor can measure?

h) (2 marks)   If the calibration curve of an instrument is not linear, where in the measurement range is the instrument most sensitive?

i) (2 marks)   What is a primary standard?

j) (2 marks)   What is the relation between RMS error and standard deviation?

Question 2. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a) (2 marks)   Why are the CCD optical sensors in some infra-red cameras cooled with liquid nitrogen?

b) (2 marks)   What is the main cause of instrument drift?

c) (2 marks)   What is a Faraday cage?

d) (2 marks)   What is meant by insertion error?

e) (2 marks)   Why is frequency modulation better than amplitude modulation when transmitting data by radio?

f) (2 marks)   What makes a measurement system 'explosion proof'?

g) (2 marks)   Single use sensors (disposable) introduce several additional sources of error beyond those associated with an individual sensor. What are some of these?

h) (2 marks)   What is common mode error and how can it be minimized?

i) (2 marks)   Why is digital data transmission more robust than analog data transmission?

j) (2 marks)   Why are sensitivity and selectivity often competing goals to be achieved in an instrument?

Question 3. (20 marks)(You only have to do three questions from questions 3 to 7.)

A thermocouple is made by connecting two dissimilar metal wires together. A voltage, dependent on the temperature, is produced by the different electron affinities of the two wires. Consider an iron-constantan thermocouple with a Seebeck coefficient of 52 $\mu V/^{\circ}C$.

a) (4 marks)   The voltages generated by the thermocouple are small but the signal to noise ratio is good. Explain why this is true.

b) (4 marks)   One disadvantage of a thermocouple is the requirement of a cold junction reference. What is a cold junction reference and why is one required?

c) (4 marks)   How would you build a cold junction reference without using ice?

Thermistors are made of a semiconductor material which changes resistance with temperature. While they produce a very large signal, the resistance change is quite non-linear. The main advantage of a thermistor is that it does not require a cold reference.

d) (4 marks)   The resistance of a thermistor can be converted to a voltage by a simple voltage divider circuit. What value should be chosen for the reference resistor to give the highest sensitivity?

e) (4 marks)   One disadvantage of thermistors is self heating. What is self heating and how can it be minimized?

Question 4. (20 marks)(You only have to do three questions from questions 3 to 7.)

Load cells are often used to weigh objects. A load cell consists of strain gages attached to a load bearing member. Consider the cylindrical load cell shown in the figure at the right:
Two strain gages are applied as shown. The load is applied axially and in response, the cylinder shortens elastically.
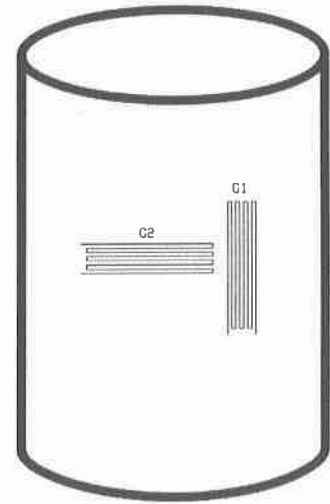
a) (4 marks) Explain why the length of the axial gage decreases while the other gage gets longer.

b) (3 marks) How could this load cell be made more sensitive to the applied weight?

c) (4 marks) If these are connected in a Wheatstone bridge configuration as shown at the right, how would you arrange the gages to compensate for temperature changes? Show this by indicating which gage replaces the appropriate numbered resistor. (example: Gx goes in place of Rx)

d) (3 marks) What type of receiving amplifier should be used to collect the weight data from Out1 and Out2? What performance characteristic must be achieved by this amplifier?
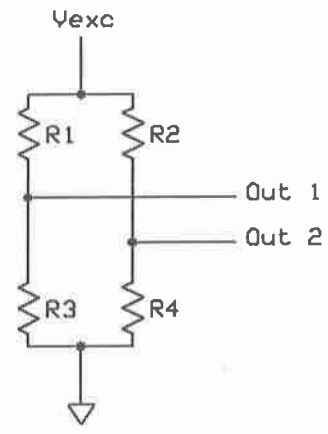
e) (6 marks) The circuit shown at the right uses a single operational amplifier to provide a single output voltage. Only one strain gage (G1) is used. If the weight applied gives a gage resistance change of δ, derive an equation giving Vout in terms of δ and the other circuit values.
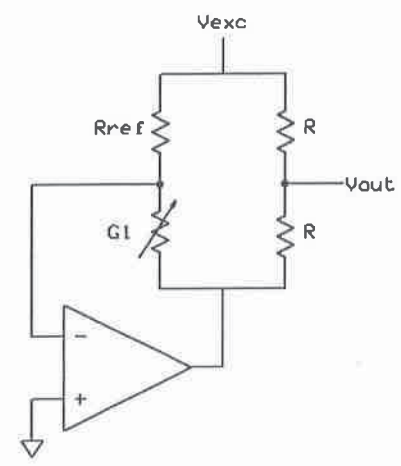
Question 5. (20 marks)(You only have to do three questions from questions 3 to 7.)

The Intersil ICL7109 is a 12 bit analog to digital converter which integrates the input signal over exactly 1/60 seconds. With de-integrate and auto-zero phases it is only capable of 30 conversions per second.

A similar system used a much faster analog to digital converter to take 256 data points equally spaced over exactly 1/60 second. These 256 samples are then averaged to provide the output. This system is capable of 60 conversions per second. Although the conversion rates are very slow, both of these converters are very useful.

a) (5 marks) Why do these two analog to digital conversion schemes completely reject North American power line interference?

b) (4 marks) The second scheme where 256 samples are averaged over 1/60 second requires an anti-aliasing filter. What cutoff frequency is required?

c) (3 marks) Why doesn't the Intersil ICL7109 require an anti-aliasing filter?

d) (3 marks) Why do these analog to digital conversion schemes also reject higher frequency noise?

e) (3 marks) What determines the conversion rate required to sample a system?

f) (2 marks) Why is averaging 256 samples very efficient?

Question 6. (20 marks)(You only have to do three questions from questions 3 to 7.)

Most measurement systems consist of several elements in series:

Receptor	Transducer	Preamplifier	Signal Processor	Data Acquisition System	Display and Recorder

a) (4 marks) The receptor is important in biological and chemical sensors. Why is it the critical element for determining the specificity of the measurement?

b) (4 marks) What does a transducer do and why is it the critical element in determining the sensitivity of the measurement?

c) (4 marks) A preamplifier is needed after many types of transducer. What are its functions and why is it critical in reducing the effects of electrical noise?

d) (4 marks) What is the purpose of the signal processing unit in preparing the signal for data acquisition?

e) (4 marks) What are the important characteristics of a data acquisition system?

Question 7. (20 marks)(You only have to do three questions from questions 3 to 7.)

Carbon monoxide is a toxic gas responsible for many deaths each year. It arises from the incomplete combustion of fuel in heating systems and internal combustion engines. Sensors are required to provide a warning of the presence of CO.

Carbon monoxide (CO) sensors typically use an electrochemical sensor where an applied voltage maintains the CO concentration in the cell at a very small constant value. The flow of CO into the cell is controlled by a diffusion barrier which makes the flow of CO linearly dependent on the outside CO concentration. The chemical reaction at the sensing electrode is:

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$$

a) (5 marks) Why is the response of this type of CO sensor linear with respect to the carbon monoxide concentration?

b) (5 marks) Fouling is a serious problem with electrochemical sensors. What is fouling and how does it affect this type of CO sensor?

c) (5 marks) The following is the basic output circuit of the CO detector. If the current Iin is -1.2μA (-1.2 microamps), what is the Vout, the output voltage?
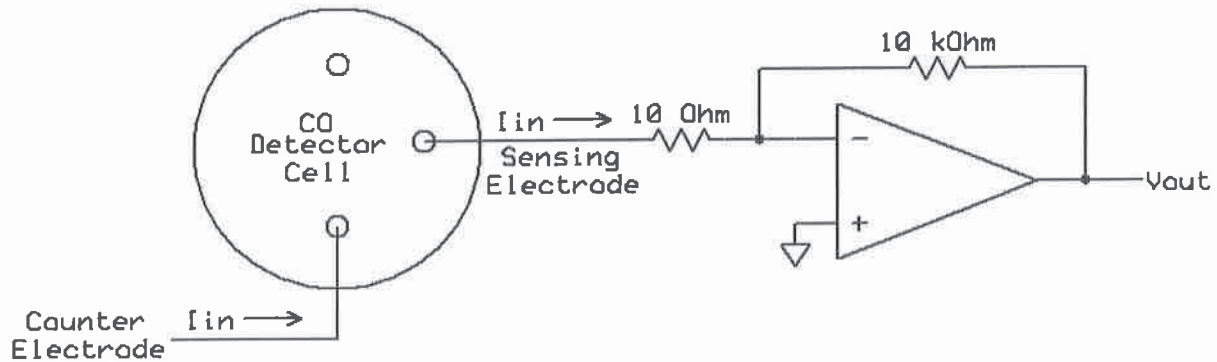
d) (5 marks) If your company will sell this type of sensor, what the liability issues may arise?