# National Exams December 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) What types of standards are available for instrument calibration?

b) (2 marks) How many data points (standard values) are required in a calibration? (A very brief explanation is needed here.)

c) (2 marks) What determines the acceptable measurement range of a sensor?

d) (2 marks) How would you measure the effect of interferences on a sensor response?

e) (2 marks) How many times should a calibration be repeated? (A very brief explanation is needed here.)

f) (2 marks) How would you determine if the sensor has a drift problem?

g) (2 marks) How would you measure the damping coefficient of a sensor?

h) (2 marks) How would you check for hysteresis during a calibration?

i) (2 marks) How would you fit a model to a set of calibration data?

j) (2 marks) How could you show that the model used is appropriate for the sensor system being fitted?

**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 amplifier noise and offset critical considerations in the first stage of an instrument system?

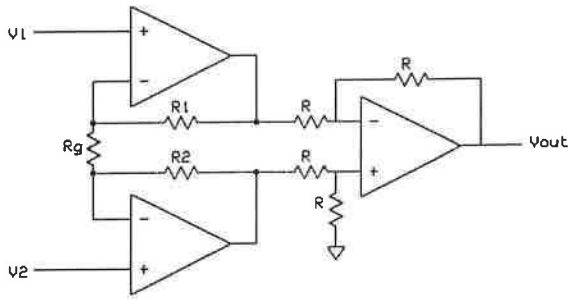
b) (2 marks) Why is a 4-20 mA current loop more reliable than a twisted pair wire carrying a differential voltage in the transmission of an analog signal?

c) (2 marks) In choosing an operational amplifier, what are some of the most important specifications?

d) (2 marks) Why can noise never be removed from a measurement?

e) (2 marks) How would you compensate for instrument drift?

f) (2 marks) A three op-amp instrumentation amplifier is shown in the schematic at the right. What are the advantages of this configuration?




g) (2 marks) What is meant by a 3½ digit voltmeter?

h) (2 marks) When high impedance sensors are used, bias currents from amplifier inputs are important. Why does there have to be a return path for these currents?

i) (2 marks) How would you connect a shielded twisted pair cable between a sensor and an amplifier?

j) (2 marks) What is an anti-aliasing filter?

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

Filled bulb thermometers as well as electrical units based on thermocouples, thermistors and RTD sensors all follow first order dynamics characterized by a time constant.

a) (5 marks) What parameters make up the time constant of a thermometer? Show that the combination of these parameters gives a result in time units (seconds).

b) (4 marks) How would you determine the time constant of a particular thermometer system?

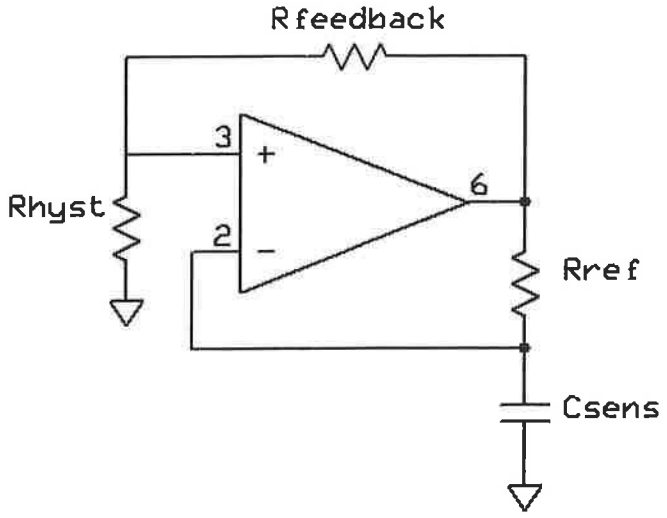
c) (5 marks) If the thermometer is placed in a liquid where the temperature of the liquid is steadily rising, a significant thermometer time constant will give a dynamic error in the readings. Describe this error.

d) (3 marks) How could you increase the speed (decrease the time constant) of a thermometer?

e) (3 marks) Describe a thermometer that doesn't require contact with the object whose temperature is being measured.

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

In some measurements, the physical property of interest can be measured as a capacity. A good example is water content. The very high dielectric constant of water makes a capacitor with the sample as the capacitor dielectric a good sensor. One way of measuring the capacity is to use a simple hysteresis oscillator like the one shown in the following schematic:




a) (12 marks) Explain the operation of this circuit and how it responds to the capacity of the sensor. Assume the output saturates at the power supply (not shown) levels of +/- 10 volts.

b) (2 marks) In measuring the moisture content of grain, why is a cylindrical container with the container at ground potential and a central rod electrode connected to Rref a very good sensor?

c) (3 marks) Why is the packing of the grain an important factor?

d) (3 marks) What other measurements might be made using a capacitive sensor?

**Question 5.** (20 marks)(You only have to do three questions from questions 3 to 7.)

Most instruments use a microcontroller to do some data processing, display and recording. The analog signal from the sensor system is captured by an analog to digital converter.

a) (4 marks) Describe the operation of a successive approximation analog to digital converter.

b) (4 marks) Why does a successive approximation analog to digital converter require a sample and hold unit on its input?

c) (4 marks) If the conversion rate of an analog to digital converter is 5000 conversions per second, what is the maximum input frequency that can be correctly sampled? Briefly explain the error that will occur if this maximum is exceeded.

d) (4 marks) If the highest input frequency exceeds the maximum that can be reliably sampled, what signal processing element is required ahead of the digital to analog converter? What is the specification required?

e) (4 marks) What is the resolution (in volts) of a 12 bit analog to digital converter that can accept a +/- 5 volt input if the input signal is +/- 1 volt? How can this resolution be improved?

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

One definition of the sensitivity of an instrument is its ability to detect small input signals.

a) (4 marks) Why is the signal to noise ratio a critical factor in determining the sensitivity of an instrument?

b) (2 marks) How is the lowest detectable signal defined?

c) (4 marks) How is the lowest detectable signal determined?

The selectivity of an instrument is its ability to reject responses to non-target interferences.

d) (2 marks) How is a selectivity ratio defined?

e) (3 marks) Relate the sensitivity and selectivity of an instrument to false positive and false negative responses.

f) (5 marks) What liability issues arise with false positive and false negative responses when detecting toxic gases?

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

The colour of an object can be described as the reflection of the primary light colours red, green and blue. One way of measuring the colour is to illuminate the object and measure the reflected light intensity at each colour. Doing this sequentially with pure colour light sources eliminates the need for expensive filters.

a) (4 marks) Why are light emitting diodes (LEDs) good sources of the required red green and blue light?

b) (4 marks) Why is a phototransistor a better sensor for dim light than a photodiode?

c) (4 marks) If three LEDs are used to provide the three light colours, but only one photodiode is used to detect the light, why must the photodiode calibrated separately with each light source?

d) (4 marks) What factors other than the object colour affect the reflectance measurement?

e) (4 marks) How would you calibrate this colour sensor?