MAE 3120

HW 04

Due 04/11

For full credit, show all your work.

1 Dynamic response of a Thermistor

A thermistor is immersed in a liquid to monitor its temperature fluctuations. The temperature (in Kelvin) varies in time as:

$$T(t) = 310 + 10\cos(2\pi t)$$

The thermistor is connected to an electronic transducer system. Overall the system responds as a first-order dynamic system with static sensitivity of 1 mV/K. A step-input calibration of the system reveals that its time constant is $\tau = 1$ s.

Assume that at $t < 0$ the thermistor is immersed in the fluid, which has a constant temperature $T = 310$ K. The sinusoidal forcing starts at $t \geq 0$.

(a) Determine the angular frequency, ω, of the temperature fluctuations.

(b) Plot the output $E(t)$ in mV for the first 30 s. On the same graph overlay the input $T(t)$.

(c) Once the system has reached steady state determine the time lag β in seconds between the output and the input.

(d) Remember the definition of the dynamic error (excluding the transient):

$$\epsilon_f(\omega) = 1 - \frac{1}{\sqrt{1 + \omega^2\tau^2}}$$

Compute it.

(e) What should be a minimal value of the time constant for the thermistor faithfully measure the temperature in the steady-state regime? Here we will consider that the thermistor is adequately sized if the dynamic error is kept below 0.1%.

(f) The definition of the time constant of a thermistor is related to the time it takes to reach thermal-equilibrium

$$\tau = \frac{mC}{hA}$$

Assume the that the thermocouple is spherical, has constant density ρ, and both the specific heat C and heat transfer coefficient h are constant. By how much would you need to reduce the radius of the thermocouple to have a faithful response?

2 Pressure Measurement

A pressure transducer is connected to a digital data-acquisition board on a computer. The characteristics of the pressure transducer and the data-acquisition system (DAS) are given below. All uncertainties are given at 95% confidence level.

Additionally, you know:

The pressure transducer output (V_{out}) is defined by its sensitivity, K, which is a function of supply voltage (V_s) and pressure P:

$$V_{out} = K(1/\text{Pa}) \times P(\text{Pa}) \times V_s(\text{VDC})$$

Here the expected pressure is up to $P = 1,000$ kPa.

Pressure Transducer Characteristics

Sensitivity: $K = 1 \times 10^{-7}$ Pa^{-1}

Supply voltage: $V_s = 10$ VDC

Range: 0-2,000 kPa

Linearity: $\pm 0.25\%$ of reading

Repeatability: $\pm 0.06\%$ of reading

Hysterisis: $\pm 0.1\%$ of reading

DAS Characteristics

Number of bits: 16 bits

Input range: $0 - 10,\ 0 - 1,\ 0 - 0.1,\ 0 - 0.01$ V

Gain error: ± 1 LSD

Linearity: ± 1 LSD

(a) What is expected range of the pressure transducer output (in Volts).

(b) Select the DAS input range that will give the best accuracy.

(c) Estimate the uncertainties (at 95% confidence level) from the pressure transducer, u_{PT} and the DAS, u_{DAS}.

(d) What is the overall uncertainty on pressure measurements made by this system.

(e) Which component contribute the most to uncertainty? Provide a scheme to reduce the overall uncertainty.

3 MTV accuracy

Molecular Tagging Velocimetry is an elegant technique to measure fluid velocity, U, in a time of flight manner:

$$U = M\frac{\delta x}{\delta t}$$

Where M is the magnification in pixel/m, δx the measured displacement in pixel, and δt the time interval over which the displacement is measured in second.

(a) How accurately can the velocity be determined if we have the following uncertainties: $u_M = 3\%$, $u_{\delta x} = 1\%$, and $u_{\delta t} = 0.0001\%$.

(b) Which term contributes the most to the uncertainty?

(b) Suppose now that the velocity must be measured with an accuracy of $\pm 2\%$. How accurate must the magnification be?

4 Taguchi Design Arrays

A company makes CMOS sensors that are to be used in scientific high-speed cameras. They want to maximize the sensor sensitivity and need to test four parameters (a, b, c, and d). A three-level experiment (with each level of each parameter repeated 3 times) is chosen. Levels 1, 2, and 3 correspond to low, medium, and high values of each respective parameter. A standard Taguchi 9-run design array is used. For each experimental run, 50 CMOS sensors are tested. For a given light source intensity, the engineers measure the recorded intensity averaged over the sensor, X_i. The results are shown in the table below.

Run#	a	b	c	d	X_i
1	1	1	1	1	2146
2	1	2	2	2	2422
3	1	3	3	3	2539
4	2	1	2	3	2572
5	2	2	3	1	2664
6	2	3	1	2	2592
7	3	1	3	2	2715
8	3	2	1	3	2357
9	3	3	2	1	2307

(a) Calculate the 12 level averages, i.e. $\bar{X}_{a1}, \bar{X}_{a2}, \ldots, \bar{X}_{d3}$.

(b) Generate 4 plots showing the dependence of X on each parameter. Make sure to label your plots properly. For simplicity, you can set level $a1$ as 1, $a2$ as 2, etc.

(c) Based on these 9 experiments, which levels of each parameter do you recommend?

(d) Is a confirmatory experiment required? If so, what are the levels to be tested?

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