Experiment A3
Sensor Calibration
Procedure

Deliverables: Checked lab notebook, Brief technical memo

Recommended Reading: Section 6.2 and Chapter 9 of the textbook

Safety First: Open-toed shoes are strictly prohibited in this lab.

Overview

In this lab, you will learn how to implement an electronic sensor known as a thermistor. Specifically, the thermistor will be placed in a voltage divider circuit, and a two-point calibration will be performed to determine the coefficients in the Steinhart Equation.

Part 1: Thermistor

In this part, you will connect the thermistor in a voltage divider circuit, as shown in Figure 1. The thermistor has a "negative temperature coefficient" (NTC), which means that its resistance decreases with temperature. The temperature in units of Kelvin T is related to the thermistor resistance R_s via the Steinhart Equation

$$T(R_s) = \left[A + B \ln\left(\frac{R_S}{R_{ref}} \right) \right]^{-1}, \tag{1}$$

where $R_{ref} = 10\text{k}\Omega$, and A and B are coefficients that you will determine via a 2-point calibration. The thermistor is typically wired up in a voltage divider circuit to convert the resistance R_S to a voltage V_{out}. This is because computers are good at recording voltages, but not so good at recording resistances.

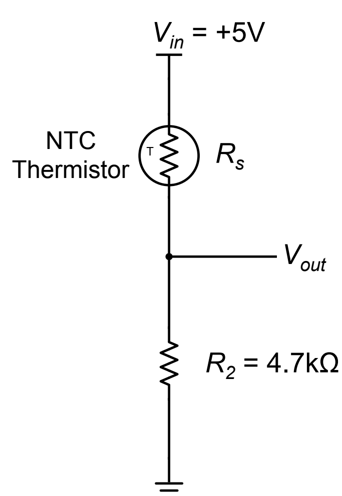

Figure 1 – A schematic of the RTD circuit.

The output voltage V_{out} of the circuit is given by the voltage divider equation

$$V_{out} = \left(\frac{R_2}{R_2 + R_S} \right) V_{in}, \tag{2}$$

where R_2 = 4.7kΩ. Equation (2) can be solved for R_S in terms of V_{out}, and substituted into Eq. (1) to give the temperature in degrees Kelvin as a function of voltage.

Procedure

Safety First: Open-toed shoes are strictly prohibited in this lab!

1. Turn on the breadboard. Use the orange Extech handheld DMM to verify that the +5V DC power supply is working.
2. Locate the thermistor. It looks like a long black wire with two pins on one end and a plastic probe tip on the other. The shiny plastic probe tip is where the sensor is located.
3. Use the handheld DMM to verify that the thermistor works. It should have a resistance around 4.7 kΩ at room temperature, and the resistance should decrease when it is warmed up in your hand.
4. Sketch the schematic shown in Fig. 1 in your lab notebook.
5. Take a 4.7k resistor out of its bin. Measure its resistance with the orange handheld DMM. Record the measured value for R_2 in your lab notebook.
6. Using the breadboard, construct the voltage divider circuit shown in Figure 1.
7. Use the **Keysight Precision DMM** to measure the voltage divider output V_{out} relative to ground.
8. Fill a beaker with ice and water from the bucket on the counter. (Be sure you have much more solid ice than liquid water.)
9. Dangle the thermistor in the center of the ice water. You should notice a change in the voltage. After the voltage reaches steady state, record it in your lab notebook. Denote this voltage as $V_{out} = V_C$ for "Cold".
10. In your lab notebook, note that the temperature of the ice water is T_C = 273K.
11. Empty the ice water into the sink. Refill it with about an inch of distilled water and place it on the hot plate. Turn the hot plate up to max temperature. Turn down the temperature when it begins to boil.
12. Dangle the thermistor in the center of the boiling water, so it is not touching the sides or bottom of the beaker. You should notice a change in the voltage. After the voltage reaches steady state, record it in your lab notebook. (It will take a few minutes to get to steady state.) Denote this voltage as $V_{out} = V_H$ for "Hot".
13. In your lab notebook, note that the temperature of the boiling water is T_H = 373K.
14. **Turn off the hot plate. Wait for the boiling water to cool.**

Part II: Take Your Temperature

You will now use the thermistor to measure the temperature of the air in the lab and the temperature in your hand.

Procedure

1. After the boiling water has cooled, dump out the beaker in the sink.
2. Record the output voltage at room temperature. Denote this voltage as $V_{out} = V_{Air}$. You will use this voltage to determine the temperature of the air in the room.
3. Firmly hold the tip of the thermistor in the palm of your clenched fist. After the voltage reaches steady state, record it in your lab notebook. Denote this voltage as $V_{out} = V_{Hand}$. You will use this voltage to determine your temperature.
4. Return the lab bench to its initial state. Disconnect all cables, and unplug everything from the breadboard.

Data Processing

Important Note: The Steinhart Equation only works if the temperature is in units of Kelvin.

1. Use the voltage divider equation to determine the resistance of the thermistor in the **ice water** $R_S = R_C$ from the measured voltage $V_{out} = V_C$.
2. Use the voltage divider equation to determine the resistance of the thermistor in the **boiling water** $R_S = R_H$ from the measured voltage $V_{out} = V_H$.
3. Use the Steinhart Equation and the two data points (T_C, R_C) and (T_H, R_H) to determine the calibration coefficients A and B. (Note that A and B should have units of K^{-1}.)
4. Use the voltage divider equation to determine the resistance of the thermistor when it was in the air $R_S = R_{Air}$ from the measured voltage $V_{out} = V_{Air}$.
5. Use the Steinhart Equation and the calibration coefficients A and B to determine the temperature of the room air T_{Air} from the thermistor resistance R_{Air},
6. Use the voltage divider equation to determine the resistance of the thermistor when it was in your hand $R_S = R_{Hand}$ from the measured voltage $V_{out} = V_{Hand}$.
7. Use the Steinhart Equation and the calibration coefficients A and B to determine the temperature of your hand T_{Hand} from the thermistor resistance R_{Hand},
8. **Important:** Write down the calibration coefficients A and B in your lab notebook. You will need them for later labs.

Deliverables

Create the deliverables listed below, import them into either Microsoft Word or LaTeX, and add an intelligent, concise caption. **Additionally, write 1 – 3 paragraphs describing the items below. Any theoretical formula you used in your analysis should be included as a numbered equation within these paragraphs.**

Important Note: The Steinhart Equation only works if the temperature is in units of Kelvin.

1. Make a table containing the parameter from Part I. (Be sure to include units!)
    a. The voltage in ice water V_C.
    b. The voltage in boiling water V_H.
    c. The resistance in ice water R_C.
    d. The resistance in boiling water R_H.
    e. The calibration constant A.
    f. The calibration constant B.

2. Make a table containing the parameter from Part II. (Be sure to include units!)
    a. The voltage measured with the thermistor in the room air V_{Air}.
    b. The resistance with the thermistor in the room air R_{Air}.
    c. The temperature of the air T_{Air}.
    d. The voltage measured with the thermistor in your hand V_{Hand}.
    e. The resistance with the thermistor in your hand R_{Hand}.
    f. The temperature in your hand T_{Hand}.

3. Write down the calibration coefficients A and B in your lab notebook. You will need them for later labs.

Talking Points – Please discuss the following in your lab report.

- Describe the two-point calibration procedure.
- Does the temperature of the air in the room seem reasonable?
- Does the temperature for your hand seem reasonable?

Appendix A

Equipment

- Keysight 34465A Precision Digital Multimeter (DMM)
    - One red banana-to-grabber cable
    - One black banana-to-grabber cable
- Extech Handheld Digital Multimeter
    - One red banana-to-banana cable
    - One red banana-to-grabber cable
- Hot plate
- Lab coat
- Heat glove
- 2x 100mL beakers
- Ice bath (solid water floating in liquid water)
- Breadboard
- 4.7k Vishay NTC thermistor NTCLE413E213F102L (Digikey part # BC2647-ND) with BLACK shrink wrap on pins