Lab # 4: Analog meets digital

In this lab you will learn how to use a microcontroller to build a temperature logger.

Background preparation

- Thermistors: Wikipedia.
- Arduino webpage
- Analog to digital converters (ADC): AOE
- Opamp follower: AOE, 4.2.3

Measuring a thermistor’s output

In this task, you will build a circuit to measure the resistance of a thermistor, a resistor whose resistance depends on temperature. The thermistor is an NTC type (negative temperature coefficient, i.e., its resistance decreases with temperature). Its nominal resistance at 25 C is \( R_{25} = 10 \, \text{k}\Omega \).

![Graph of resistance versus temperature for a negative temperature coefficient (NTC) thermistor. The quantity \( R_{25} \) is the nominal resistance of the thermistor at 25 C.](image)

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1The thermistor you will use is a Vishay # NTCLE100E3103HB0.
The thermistor’s datasheet provides the following formula for converting its resistance to temperature (in Kelvin):

\[
\frac{1}{T(R)} = A_1 + B_1 \ln \frac{R}{R_{25}} + C_1 \left( \ln \frac{R}{R_{25}} \right)^2 + D_1 \left( \ln \frac{R}{R_{25}} \right)^3.
\]  

(1)

The constants for this thermistor type (in units of \( K^{-1} \)) are \( A_1 = 3.354016 \times 10^{-3}, \) \( B_1 = 2.884193 \times 10^{-4}, \) \( C_1 = 4.118032 \times 10^{-6}, \) \( D_1 = 1.786790 \times 10^{-7}. \)

a) Measure the resistance of the thermistor, \( R_{th} \), using a multimeter. Record the room temperature, \( T_{room} \), and verify that \( R_{th} \) is consistent with the curve shown in Figure 1.

b) In order to automatically record the thermistor’s resistance, it is convenient to produce a voltage that depends on its resistance. You will do this using a voltage divider.

Wire up a resistive divider circuit as shown in Figure 2. Use a value of \( R_{ref} \) between 1-5 k, and \( V_{in} \) of +5 V. Measure and record the value of \( R_{ref} \) before you put it in. Measure the output voltage of the divider when you touch the thermistor’s head with your fingers. Estimate your hand’s temperature using the calibration curve in Figure 1 and the calculated division ratio of the divider.

**Figure 2: Divider circuit to convert the thermistor’s resistance to a measurable voltage.**

(30 mins)

**Arduino microcontroller**

As you observed in the previous task, the voltage produced by the thermistor divider circuit is a complicated function of the temperature. Wouldn’t it be convenient to somehow directly convert the thermistor’s output into a temperature? In this task, you will use a digital device called a microcontroller (uC) to automate this calculation. Microcontrollers are extremely versatile devices, and are handy for many tasks where complicated algorithms and nonlinear operations need to be implemented.
a) Plug in your uC board into any available USB port on the computer. (You may disconnect the “LabDAQ” instrument if necessary.) Start up the Arduino program on the desktop, and configure the software to communicate with an Uno board. Make sure that the Board is chosen to be “Arduino/Genuino Uno”, and the Port is chosen correctly for the uC that you plugged in.

To upload a program (called a “sketch”) to the uC board, you will need to first compile it (indicated by the Verify button, shaped like a check mark), and upload it (using the button shaped like a right arrow). Try the simple Blink example first, and modify the code so that you get familiar with the programming interface.

Next, set up a potentiometer to generate a variable DC voltage, and learn how to measure voltages using the Arduino. You can use the AnalogReadSerial example sketch as the basis for your program.

**Warning:** Never send in voltages outside the range of 0 to +5 V into the analog input pins of the uC. If you exceed this range, you may destroy the microcontroller’s ADC.

Feel free to try out some of the other examples as well.

(45 mins)

**Opamp follower**

The input impedance of the ADC on the microcontroller is not sufficiently high. If you attach the ADC of the microcontroller directly to the thermistor divider, its input impedance will load the divider circuit and lead to inaccurate voltage measurements. Therefore we will construct an opamp follower to sit between the divider and the microcontroller. The follower presents a large input impedance to the divider, and a small output impedance to the microcontroller.

a) Wire up an opamp follower using an LF356, as shown in Figure 3. Apply a variety of waveforms to the input of the follower, and verify that the output faithfully tracks the input.

![Figure 3: Opamp follower.](image-url)

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2The Blink and AnalogReadSerial examples can be found under File → Examples.
b) Connect the thermistor divider circuit to the input of the follower, and connect its output to one of the uC’s analog inputs. Write a uC program to convert the output of the thermistor circuit into temperature, and print out the temperature measurements on the serial port. A basic program to get you started (arduino_thermistor.pde) is available on the course webpage.

(60 mins)