Lab 4: Analog Measurements   Should be done by mid-April

Background

Over the summer you have a job working for a medical technology start-up in Rochester, MN. The company is working on a high-precision infra-red incubator to be used in the maternity ward of hospitals for newborn babies, and you're excited to be able to help on the project.

In your first week, your boss asks you to familiarize yourself with temperature measuring equipment (obviously, the incubator can't allow the baby to be chilled or overheat, and the control circuitry has to be designed accordingly). The specific device she wants you to work with is an LM34 or TMP36 temperate probe, which is made by National Semiconductor (among others).

Please read the appropriate datasheet.

The specific wiring diagram for the LM34 is given in the datasheet. From reading through the datasheet, you should be able to determine supply/signal values and the numerical conversion from the sensor voltage to temperature, measured in degrees Fahrenheit.

You should be able to supply V_Supply and GND from your Arduino, and V_OUT can be read either with a voltmeter or one of the analog-to-digital (A2D) pins on your Arduino.

Data Collection

After wiring up your sensor, please take data (using a glass thermometer as a control), which characterizes the behavior of the sensor. Please make sure your data allows you to answer the following questions:

1. What pin, and in what way do you measure sensor voltage?
2. How do you convert the sensor voltage into a sensor temperature?
3. How long does it take the sensor to equilibrate with its surroundings? [1]
4. What's the min/max surface temperature of your body? (be modest!)
5. How does the value read from the LM34 compare (in accuracy) to a reading from the standard glass thermometer?
6. Is the calibration formula given in the datasheet reliable?
7. To what accuracy does the sensor and the ADC allow you to measure temperature?

Building a model

With data collected, please build a mathematical model which allows you to predict sensor temperature based on the voltage the sensor reports. To create this model, you probably want to make a graph of sensor temperature as a function of output voltage. A mathematical model should be accessible from the data you plot. Note, your graph is likely very similar to that in the spec sheet.

[1] In Heat Transfer, the relevant idea is called “Lumped System Analysis”

Building an Algorithm

From what you already know about Arduinos, please create an algorithm which illustrates the following procedure. With the sensor is in contact with an object whose temperature we wish to measure, and the Arduino set up to measure the sensor's analog voltage:

1. The Arduino reads this voltage via an A2D pin.
2. The Arduino converts the integer A2D value into a temperature, in Fahrenheit (using your model, above).
3. The Arduino sends the temperature reading and a time measurement to the serial monitor (e.g., your laptop).
4. The Arduino waits a specified time, and then repeats the sequence of procedures.

Once you have an algorithm sketched out, please build and test code which executes it.

Deploying the model

Finally, please solve at least 3 of the following design problems, which make use of your model and algorithm.

1. In the infant incubator, the IR heating lamp should turn on if the sensor reads an infant finger temperature lower than $\mathrm{T}_1 = 98.0°\mathrm{F}$, and further, the heating lamp should turn off when the temperature exceeds $\mathrm{T}_2 = 100.0°\mathrm{F}$. Using your model and initial algorithm, create and implement a new algorithm which executes this temperature-control procedure. You can represent the heater's function via an LED, which would be driven by the Arduino. In an actual design, the Arduino would drive a relay or transistor, which controls the heater.

2. Children are precious, and it won't do to trust the life of a child to a single $0.76 component. For greater safety and reliability, consider an improved design which would read in values from two temperature sensors and actuate a heater if and only if both sensors agree. Create and implement such an algorithm. A better design might throw an error light if the sensors disagree.

3. A rice cooker has two heater settings, the first to get the rice+water up to boiling, and a second heater setting to keep the rice warm once it has fully cooked. I've heard that there's one heater and the drive cycle is a basic PWM function. Design and implement an algorithm to model the function of a rice-cooker. You can use an LED's (with variable brightness, or perhaps an RGB LED) to represent the function of the two heater states.

4. Read the temperature of your fingertip and report the temperature to the serial monitor or a 2x8 LCD display. Use an RGB LED to show when the temperature of our fingers is not yet known (eg yellow? because the temp is rising) and when the temp is stable (green, because the temp is now holding constant).

5. Build a cooling system that turns on a fan when the temperature rises above a given setpoint. Eg, if T is within 2C of the setpoint, the fan should turn on at low speed. If T is more than 2C above the set point the fan should run at high speed. Control the fan by sending a PWM signal to a transistor that connects the bottom of the fan to ground. A variable setpoint can be created with a potentiometer and fixed resistor wired in series, with the divided voltage mapped to an ADC input pin.

6. Whenever you open a refrigerator door, cold air leaks out and the compressor runs to cool down your food. Create and implement a data collection algorithm that would allow you to capture this data to see how much time it takes to cool the fridge down to proper temperature after the door has been opened. Once you have the apparatus built, run the test on a fridge (note, you may want to solder long leads onto the temperature sensor).

7. Instead of a temperature sensor, read analog voltage from a distance sensor and do something interesting with the data. Ie, read a distance, and flash a light or buzzer faster (10Hz, 20Hz, 30Hz…) as the distance measured decreases. (think about a backing up warning signal for a lorry).

8. In general, the mathematical equation describing the temperature, T, of an object in contact with a larger heat reservoir with temperature, T_H, is given by $\frac{\mathrm{dT}}{\mathrm{dt}} = -\kappa(\mathrm{T} - \mathrm{T_H})$. Solve this equation, and compute κ for the conditions that your fingers are the "infinite heat reservoir" that the TMP36 is in contact with.