ME224 Lab 4 – Temperature Controller

Introduction:

You have now completed three labs meant to get you up to speed and now you are ready to do some experiments. In this lab you will build a temperature controller. You will use the techniques learned in the last three labs as well as a couple more that you will cover in the beginning of this lab.

The objective of this lab is to control the temperature of a small aluminum block. As you do this lab you should learn how to use a transistor as a switch, calibrate a transducer, and write simple control programs in LabVIEW.

The apparatus used in this circuit is simple. There is a small round block of aluminum with several holes drilled into it. These holes allow the imbedding of a resistance heater, a thermistor, and a thermometer. There is a simple circuit board attached with breadboarding for connection to the circuitry you build during the lab.

The ultimate goal is to monitor and control the temperature of the aluminum block. To do this you will go through the following steps:

1. Build a circuit to allow operation of the heater by hand.
2. Perform an initial experiment to learn the characteristics of the system.
3. Build a signal conditioner for the thermistor.
4. Write LabVIEW code to read the thermistor and calculate its resistance.
5. Write LabVIEW code to collect and save calibration data.
6. Use Excel or LabVIEW to analyze the calibration data.
7. Build a circuit to allow the computer to control the heater.
8. Write LabVIEW code to control the system

The deliverables for this project are as follows:

1. Curve fitting technique used for your data
2. Printed graph of the control system working as described in part c of the final project.
3. Printout of your code.

Measuring the temperature

There are several ways to measure temperature including thermistors, thermocouples, and dedicated IC’s. In this lab we will use the thermistor. The **thermistor** is a
device that changes resistance with changes in temperature. The resistance of conductors (metals) increases with increasing temperature. Yet for a thermistor, resistance decreases with increasing temperature according to the relation $R = R_0 \exp(T_0/T)$. In this expression, $R$ is resistance (ohms); $R_0$ is a resistance value corresponding to infinite temperature; $T_0$ is an activation temperature (K); and $T$ is the absolute temperature (K). The difference between a conductor and a thermistor is that the thermistor is made from semi-conducting materials.

**Activity 4.1 Specific Heat and Power**

This activity is a warm up for a later one and uses the thermistor circuit but not the computer or data acquisition board.

The **specific heat** $C$ of a substance is the ratio of the amount of heat added ($dQ$) to the corresponding temperature rise ($dT$) per unit mass ($m$):

$$C = \frac{dQ}{m \, dT}$$

The **power** $P$ is defined to be the change in heat ($dQ$) with a change in time ($dt$),

$$P = \frac{dQ}{dt}$$

So the amount of heat added to the aluminum block by the heater is the power times the time: $dQ = P \, dt$. Where the power is the voltage drop $V$ times the current $I$. $P = VI$ or by using Ohm’s law, $P = V^2/R$ where $R$ is the resistance.

**Procedure:**

1. Build circuit 4.1 (Appendix A) so that you achieve manual control of the heater.

2. Measure the resistance $R$ of the heater.

3. While pushing the button, determine how rapidly the temperature rises (deg/sec). By estimating the mass of the aluminum block (assume D12mm × L21mm solid rod), estimate its specific heat. You may take the density to be 2702 kg/m$^3$. Compare your rough results with the specific heat of aluminum from a reference manual 903 J/kg-K. Where does the error enter this estimate?

4. Also measure the rate at which the system cools and calculate the heat loss per unit time (the power output) due to conduction and convection. Is this result significant for the measurement made in part a?

5. When you release the button, why doesn’t the temperature stop rising immediately?

In the laboratory, both the thermometer and the thermistor have finite time responses to a change in temperature. However, the time constant of the thermometer is much larger and so it dominates the response of the system. The order of the time constant $\tau$ of the thermometer can be roughly estimated to be 1.5 sec by watching the temperature reach equilibrium (at about 5 $\tau$) after the power input is stopped (the button is released, i.e., $t=t_0$). In the following, the purpose is to calculate the time constant $\tau$ of
the thermometer by estimating the temperature lag of the thermometer behind the block temperature for a constant power input (i.e., when the button is kept pushed down, how much does the actual temperature $T_{\text{block}}$ lag the measured temperature $T_m$?).

Activity 4.2 Reading the thermistor with a Data Acquisition Card (DAQ)

Procedure:

1. Now build Circuit 4.2 (in Appendix A). Since the resistance of the thermistor will range between 100 and 2K ohms (roughly! Measure it by yourself) you will need to build a signal conditioning circuit to shift the voltage and amplify it so that the Analog-to-Digital-Converter (ADC) input ranges from -10 to +10 volts. In the last lab you designed and built an op amp circuit to shift and amplify a voltage to a -10 to +10 range (see lab 3 Activity 3.4), and you need to use that circuit in this activity.

2. Measure the resistances of the thermistor beforehand directly using the thermistor pins at +25°C and +80°C.

3. Calculate the corresponding voltage drop on the thermistor at +25°C and +80°C.

4. Design the difference op-amp circuit as you did in lab 3 (Activity 3.4) to have an output that ranges from -10 to +10 volts. Note that your circuit output should be -10V at 25°C and +10V at 80°C.

5. After you build this you will now have to attach this circuit to the temperature controller apparatus and the data acquisition board. Test the circuit by manually operating the heater and checking the output with the oscilloscope. Attach the output of the circuit to any ADC channel of the USB-6009. You can now write a short program in LabVIEW to verify the USB-6009 is working if you like. Or if you are more confident in your troubleshooting skills jump to the next step.

Activity 4.3 Calibrating the thermistor

Now you can read the voltage of the thermistor but what temperature does that voltage correspond to? The purpose of this step is to calibrate the thermistor so that you can control the temperature of the aluminum block using the voltage values you read from the thermistor. To do this you will take several readings (20+) of the actual temperature (displayed on the thermometer) and the corresponding voltage of the thermistor. Later you will fit this data to a curve.

Write a LabVIEW program that will allow you to manually enter a temperature you read from the thermometer and immediately take a reading of the thermistor voltage using the USB-6009. The program should take 20+ readings and save all the data to a text file (temperature entered, voltage value from ADC and corresponding resistance value of the thermistor). Additionally, calculate the resistance of the thermistor.
Note: 1) Convert the voltage into the resistance of the thermistor using basic circuit equations for voltage divider and other.

Activity 4.4. Thermistor Data Plot

Using the graphing method available to you (such as Excel), plot the thermistor resistance vs. temperature. It is necessary to use degrees Kelvin in later exercises so scale the data appropriately and plot the temperature in degrees Kelvin. Eventually you need to store these calibration data into the computer and use them later in the control program. Since there are several ways (e.g., (1) data array and interpolation, (2) math approximation: polynomial, log, exp...etc. basic functions, (3) least square method) to do that, it is left open to you to find a better way of storing data and still keep your data within accuracy as you use them. Explain how you are going to do this.

The value of graphical plots is that they are capable of displaying and conveying much information very quickly. One obvious weakness of the linearly scaled display of the resistance vs. temperature plot that you have made is that it is difficult to get a good display of the lower values of resistance. When the numerical value of a parameter to be plotted spans a large range, scaling the axis logarithmically is very useful. On a linearly scale axis each increment of length is proportional to an increment of the parameter being plotted. On a logarithmically scaled axis each increment of length is proportional to the fractional change in the value of the parameter. (If \( y = \log(R) \), then \( dy = dR/R \).) Often it is more significant to note the fractional change in a parameter than the change in the value of the parameter itself.

Logarithmic plot

Modify your plot to use a logarithmic scale on the ordinate. Note that using a logarithmic scale is different from plotting logarithmic value on a linear scale although the shape of the resulting curve is the same. Some plotting programs do not have the capability of displaying logarithmic scales so logarithmic values on a linear scale will have to do. Put your logarithmic plot in the report.

This logarithmic plot is a very useful one to display the resistance of a thermistor vs. temperature for purpose of manually determining the resistance for a given temperature. However, for comparison with mathematical theory it is better to use a different plot. The form of the plot is determined by the particular phenomena being studied. As shown earlier, the variation of the resistance of a thermistor can be written as:

\[
R = R_0 \exp \left( \frac{T_0}{T} \right) \quad (1)
\]
where $R_0 (\Omega)$ and $T_0 (K)$ are constants. To display graphically the extent to which the measured dependence conforms to this theoretical dependence, it is useful to plot the resistance vs. temperature using a scale such that the resulting plot becomes a straight line. This is easily done by taking the natural logarithm of the resistance for the ‘linear’ ordinate length and $1/T$ for the ‘linear’ abscissa length scale. Taking the logarithm of Equation (1) gives

$$\ln(R)=\ln(R_0)+(T_0/T) \quad (2)$$

and by setting

$$y=\ln(R) \quad A=T_0 \quad x=1/T \quad B=\ln(R_0)$$

Equation (2) becomes

$$y=Ax+B \quad (3)$$

which is a straight line.

You should now have all the information you need to calculate the temperature from the voltage of the thermistor. If you use the linear interpolation method shown above you have performed a linear regression to calculate the values of $A$ and $B$ and can easily solve the equation.

The next step is to learn how to turn the heater on and off using the USB-6009 so that the control can be fully automated. You will use the digital port and a transistor to run the heater. Use MAX to create a digital I/O task and choose “Line Output” for the type of task.

**Transistors**

Transistors are the building blocks of modern electronics. The op-amp is actually a pre-packaged circuit built of transistors and so is your computer. We could spend a whole year teaching you the ins and outs of them but instead we have introduced the transistors in class and now we will simply teach you a couple of ways they are useful in circuits. Transistors make great computer controllable switches and power amplifiers. In this lab you will need to turn on and off a small heater and also a fan. The voltage and current that your USB-6009 is capable of is much too small to handle this task easily so you will build a switch from a transistor to use an external power supply to run the heater. This circuit is shown in Circuit 4.3.
Activity 4.5 A simple temperature controller Natural Convection

Write a program for a temperature controller as described below. The program should ask you to type in a temperature. The computer should then turn the power to the heater on and off in response to thermistor voltages read. (You are encouraged to add a simple LabVIEW program to control the fan so as to accelerate the cooling process). Run the program and demonstrate to your laboratory instructor that the thermometer does stabilize to the temperature typed in. When testing be sure to turn off the heater manually or with a program statement at the end of your program to ensure that the heater doesn’t overheat.

a. You will be asked to examine the performance of your control program running over your system at a chosen temperature that ranges from 40° C to 80° C. The basic requirement for your control program is that it can actually approach to the typed-in temperature within ±1.5° C for at least 1 minute.

b. Explain what technique you use in retrieving your calibration data for your control program.

c. Being a modern engineer, you also need to persuade your future boss or customer that your control program really works. Therefore, some evidence should be prepared and submitted in the following format.

1. A printout of the real-time temperature response of the system and digital output to the heater. These information should contain $T_{thermometer}$, $T_{thermistor}$, and $D_{heater}$ (on or off, 1 or 0) with respect to time, in a manner that the span of the tracing time is about 2~4 minutes and the sampling rate is 0.5~1 point/sec (except $T_{thermometer}$, 0.2 point/sec is needed). Of course, $T_{thermistor}(time)$, $T_{thermometer}(time)$, and $D_{heater}(time)$ should share the same axis to have meaningful results, however it is difficult to record $T_{thermometer}$ directly into the computer (no sensor transmitting the temperature reading directly) thus you need a digital watch to manually record the data and then save it into a datafile. Give a printout of your experiment data.

2. Once you have all the data mentioned above ready, you could demonstrate them in figures. Put $T_{desired}$, $T_{thermistor}$, and $T_{thermometer}$ with respect to time into one figure and $D_{heater}$ with respect to time in another figure. Note that these two figures are still related by the same time axis.
# Appendix A: Circuit Diagrams

<table>
<thead>
<tr>
<th>Circuit Diagram</th>
<th>Notes</th>
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| ![Circuit Diagram 1](image1.png) | RT – Resistance of Thermistor  
RH – Resistance of Heater  
(showed on the heater board)  
Switch – close/open wires to check if the heater works (LED should be on/off)  
Measure the heater resistance by yourself. |
| ![Circuit Diagram 2](image2.png) | RT – Resistance of Thermistor  
RH – Resistance of Heater  
!!! Build amplifier circuit  
Measure the Thermistor resistance by yourself. |
| ![Circuit Diagram 3](image3.png) | RT – Resistance of Thermistor  
RH – Resistance of Heater  
DAC (P0.0) is a part of the USB-6009 (Digital output operation)  
Transistor IRZ22 (switch function):  
S – source 2  
G- Ground 3  
D- drain. 1 |
Sample Digital I/O Program