Thermistor Lab

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2.688 Oceanographic Systems

Question 1:

Reference Temperatures

- Cold Water 0.9 deg C
- Warm water 25.5 deg C

Big thermistor

- Ice Water 31.82 kΩ
- Warm water 9.15 kΩ

Small thermistor

- Ice Water 28.46 kΩ
- Warm water 9.9 kΩ

Computing betas - used the following equation and the reference values above for each thermistor:

$$\beta = \frac{\ln(\frac{R_{T1}}{R_{T2}})}{(\frac{1}{T_1} - \frac{1}{T_2})}$$

```
r_ref_1 = 31.82*1000;
r2 = 9.15*1000;

t_ref_1 = 0.9 + 273.15;
t2 = 25.5 + 273.15;

b1 = log(r_ref_1/r2)/((1/t_ref_1)-(1/t2));
fprintf("Big thermistor beta: %f", b1)
```

```
Big thermistor beta: 4146.619163
```

```
r_ref_2 = 28.46*1000;
r2 = 9.9*1000;

t_ref_2 = 0.9 + 273.15;
t2 = 25.5 + 273.15;
```

```
b2 = log(r_ref_2/r2)/((1/t_ref_2)-(1/t2));
fprintf("Small thermistor beta: %f", b2)
```

```
Small thermistor beta: 3513.230743
```

Resistance-temperature table

$$R(T) = R_{\mathrm{ref}} e^{\beta\left(\frac{1}{T} - \frac{1}{T_{\mathrm{ref}}}\right)}$$

```
reference_temps = -40:20:200;
reference_temps_kel = reference_temps + 273.15;
s1_kOhms = r_ref_1*exp(b1*(1./(reference_temps_kel)-1/t_ref_1))/1000;
s2_kOhms = r_ref_2*exp(b2*(1./(reference_temps_kel)-1/t_ref_2))/1000;

%display([reference_temps; s1_kOhms; s2_kOhms])
display(table(reference_temps', s1_kOhms', s2_kOhms', ...
    VariableNames=["Temperature (C)", ...
    "Big thermistor resistance (kOhms)", ...
    "Small thermistor resistance (kOhms)"]))
```

13×3 table

Temperature (C)	Big thermistor resistance (kOhms)	Small thermistor resistance (kOhms)
-40	452.33	269.72
-20	110.97	82.014
0	33.447	29.688
20	11.873	12.345
40	4.8107	5.7421
60	2.1726	2.928
80	1.0736	1.6114
100	0.57217	0.94544
120	0.3251	0.58563
140	0.19511	0.37998
160	0.12275	0.25659
180	0.080449	0.17938
200	0.054643	0.12925

With only two reference points, the accuracy of the calibration for both sensors is quite low. The resulting calibration of the large thermistor is better at higher temperatures, and the calibration of the small thermistor is better at lower temperatures, and they have comparable accuracy in the range near the temperatures used for calibration (0-20 C). This inaccuracy is likely caused by the relatively narrow range of the temperature values used for calibration, the fact that only two points were used to compute the betas, the equation used for calibration, and the fact that the reference temperature was measured by a probe with only one decimal of precision.

Question 2i

In microvolts:

- Big Thermistor, warm bath: -171456
- Big Thermistor, cold bath: -1248320
- Small Thermistor, warm bath: -150400
- Small Thermistor, cold bath: -1269376

Computed Temperatures:

$$R_x = -\frac{R(\frac{V_o}{V_i} + \frac{1}{2})}{(\frac{V_o}{V_i} + \frac{1}{2}) - 1}, \; T(R) = \frac{1}{\frac{\ln(\frac{R}{R_{\mathrm{ref}}})}{\beta} + \frac{1}{T_{\mathrm{ref}}}}$$

```
microV_measured = [-171456, -1248320, -150400, -1269376];
R_measured = zeros(1,4);
T_measured = zeros(1,4);

b_list = [b1, b1, b2, b2];
r_ref_list = [r_ref_1, r_ref_1, r_ref_2, r_ref_2];
t_ref_list = [t_ref_1, t_ref_1, t_ref_2, t_ref_2];

r = 10000;
v_i = 5;

for i=1:length(microV_measured)
    % Extract reference
    r_ref = r_ref_list(i);
    t_ref = t_ref_list(i);
    b = b_list(i);

    v_o = microV_measured(i)/1000000; % Convert to volts
    a = -v_o/v_i + 1/2; % Save value in parenthesis
    R_measured(i) = -r*a/(a-1); % Compute resistance
    T_measured(i) = 1/(log(R_measured(i)/r_ref)/b + 1/(t_ref)) - 273.15; %
Compute temperature (in celsius)
end

T_measured
```

- Big Thermistor, warm bath: 20.7
- Big Thermistor, cold bath: 2.0
- Small Thermistor, warm bath: 22.2
- Small Thermistor, cold bath: -0.7

Reference Temperatures

- Cold Water 0.9 deg C

- Warm water 25.5 deg C

The measured values are approximately equal to the measured temperatures. The errors can likely be attributted to the imprecise calibration, and variations in the water bath temperature (by observation, the water bath seemed to change +/-2 degrees whether they were stirred or not.)

Question 2ii

Circuit sensitivity definition: "how much a particular characteristic changes as a particular component value changes"

Changing component: resistance

Output: temperature

```
dv_o = v_i/2 + 188/1000000;
a = -dv_o/v_i + 1/2; % Save value in parenthesis
dR = -r*a/(a-1); % Compute resistance
dR
```

```
dR = -0.3760
```

```
% Assuming 10k ohms = 25 C, as indicated by spec sheet
r_ref = 10000;
t_ref = 25 + 273.15;

% Compute temperature difference between r_ref and r_ref + dR
1/(log((r_ref+dR)/r_ref)/b + 1/(t_ref)) - t_ref
```

```
ans = 9.5136e-04
```

For measurements around 25 deg C, (thermistor resistance of 10k ohms, equal to resistors used for bridge)

ADC Resolution: 1 bit = 188uV $\approx$-0.376$\Omega$$\approx$0.00095 C

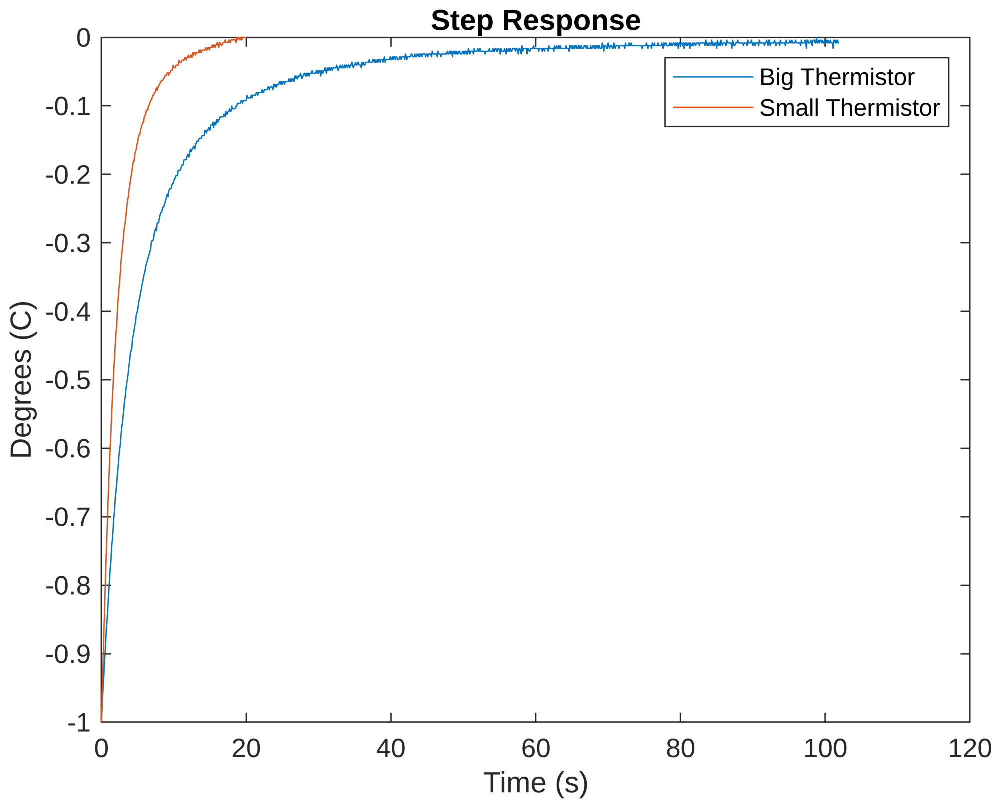
Question 2iii

The simple bridge circuit is less sensitive than the Wheatstone bridge since the same change in resistance translates to a larger difference in the voltage output in the simple circuit. The 1 bit -> 188uV resolution limitation of the ADC means that this effectively increases the minimum detectable change in resistance (and consequently, temperature), thus decreasing the sensitivity of the measurement.

Question 3

```
% Tables for sensor 1 and sensor 2
tab_s1 = readtable('big_ice_temp.csv');
tab_s2 = readtable('small_ice_temp.csv');

% Sampling interval
```

```
dt = 0.1;

% Extract data
temp_s1 = tab_s1.Var2(2:end);
ts_s1 = 0:dt:(length(temp_s1)-1)*dt;
temp_s2 = tab_s2.Var2(2:end);
ts_s2 = 0:dt:(length(temp_s2)-1)*dt;

% Extract step response
% Use raw impulse values to find "start"
raw_impulse_s1 = step2impulse(temp_s1,dt);
start_idx_s1 = find(raw_impulse_s1 == min(raw_impulse_s1));
raw_impulse_s2 = step2impulse(temp_s2,dt);
start_idx_s2 = find(raw_impulse_s2 == min(raw_impulse_s2));

% Crop data to step
cropped_s1 = temp_s1(start_idx_s1:end);
cropped_s2 = temp_s2(start_idx_s2:end);
cropped_ts_s1 = ts_s1(1:end-start_idx_s1+1);
cropped_ts_s2 = ts_s2(1:end-start_idx_s2+1);

% Ensure zero baseline
baseline_s1 = cropped_s1 - min(cropped_s1);
baseline_s2 = cropped_s2 - min(cropped_s2);

% Rescale data based on step size
step_s1 = baseline_s1/max(baseline_s1);
step_s2 = baseline_s2/max(baseline_s2);

% Flip sign since our input was cold water
% (data collected for 0 to -1 instead of 0 to 1)
step_s1 = -step_s1;
step_s2 = -step_s2;

figure
plot(cropped_ts_s1, step_s1, DisplayName='Big Thermistor')
hold on
plot(cropped_ts_s2, step_s2, DisplayName='Small Thermistor')
title('Step Response')
legend()
ylabel('Degrees (C)')
xlabel('Time (s)')
hold off
```

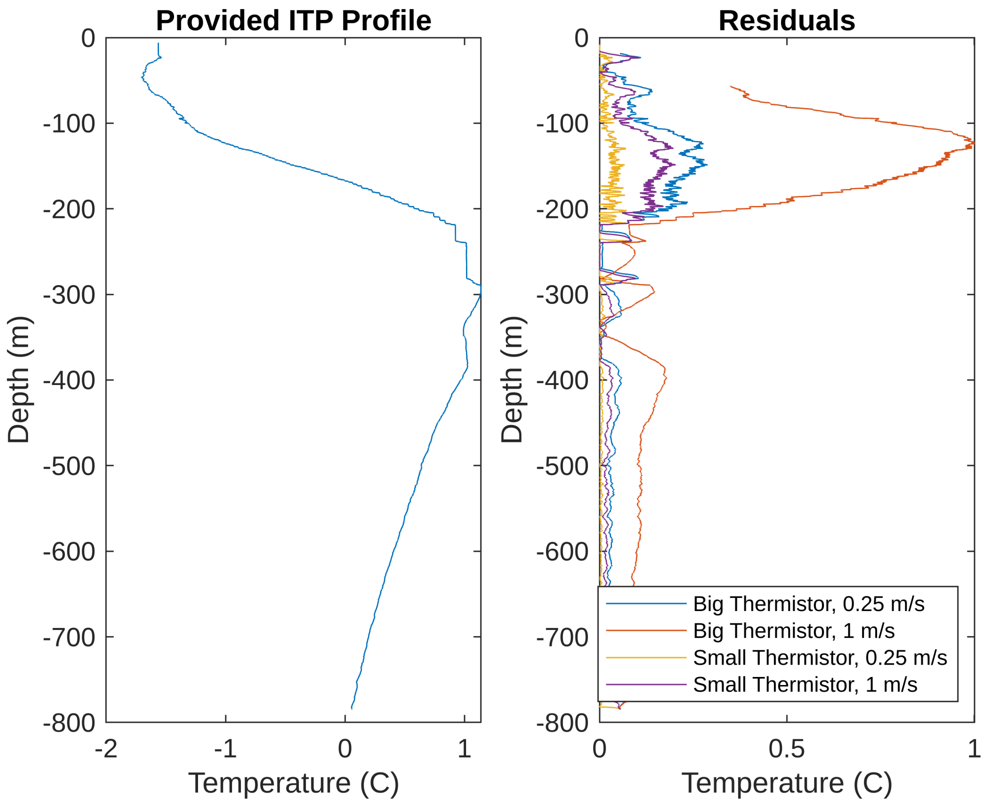


The step response for the small thermistor converges to 0 in less time than the response for the big thermistor, which implies that the small thermistor will need less time to take a temperature measurement than the big thermistor. The big thermistor will need more time to "acclimate" to the temperature before the measurement is recorded.

Question 4

```
load itp48_prof1.mat

% Compute impulse response
impulse_s1 = step2impulse(step_s1,dt);
impulse_s2 = step2impulse(step_s2,dt);

% Create array of depths given speed and sampling interval (dt)
v1 = 0.25; % m/s
v2 = 1; % m/s

depths_v1 = 0:dt*v1:max(depth);
depths_v2 = 0:dt*v2:max(depth);

% Lookup temperature values at timestamps
temp_interp_v1 = interp1(depth, temp, depths_v1);
temp_interp_v2 = interp1(depth, temp, depths_v2);

% Apply convolution to signal using impulse response
```

```
% Multiply by dt to account for "scale"
s1_v1_meas = conv(temp_interp_v1, impulse_s1,'same')*dt;
s1_v2_meas = conv(temp_interp_v2, impulse_s1,'same')*dt;
s2_v1_meas = conv(temp_interp_v1, impulse_s2,'same')*dt;
s2_v2_meas = conv(temp_interp_v2, impulse_s2,'same')*dt;

% Compute residuals
s1_v1_residual = abs(temp_interp_v1 - s1_v1_meas);
s1_v2_residual = abs(temp_interp_v2 - s1_v2_meas);
s2_v1_residual = abs(temp_interp_v1 - s2_v1_meas);
s2_v2_residual = abs(temp_interp_v2 - s2_v2_meas);

subplot(1,2,1);
plot(temp, -depth)
ylabel('Depth (m)')
xlabel('Temperature (C)')
title('Provided ITP Profile')

subplot(1,2,2);
plot(s1_v1_residual, -depths_v1, DisplayName='Big Thermistor, 0.25 m/s')
hold on
plot(s1_v2_residual, -depths_v2, DisplayName='Big Thermistor, 1 m/s')
plot(s2_v1_residual, -depths_v1, DisplayName='Small Thermistor, 0.25 m/s')
plot(s2_v2_residual, -depths_v2, DisplayName='Small Thermistor, 1 m/s')
ylabel('Depth (m)')
xlabel('Temperature (C)')
title('Residuals')
legend('Location','southeast')
hold off
```



When the temperature changes rapidly over a short depth, the dynamic response of the thermistor can introduce strong artifacts in the data. In particular, when profiling at fast speeds with the big thermistor, strong artifacts can emerge because the probe doesn't have enough time to match the temperature of the water, which will result in a measured profile that appears "smoother" than the actual temperature profile.

The thinnest resolvable layer depends on the temperature difference between the water in the layer and the rest of the water column - the bigger the difference between the two, the thicker the layer will need to be to be measured accurately. As a ballpark estimate, let's assume the temperature difference is 1 degree C. From the graph in Question 3, we can find time on the x-axis that intersects the y-axis value -0.1, which correlates to the time required to take a measurement within a tenth of a degree. For the big and small thermistors, it will take 19 and 6.5 seconds, respectively, to satisfy this accuracy requirement. For some temperature difference dT, we can rescale the step response accordingly, then repeat this analysis.

When profiling slowly, (0.25 m/s), 19 and 6.5 seconds translates to a minimum thickness of approximately 5m for the big thermistor and 1.5m for the small thermistor.