Project #2

Precision Temperature Measurement using Advanced Data Acquisition Module and Thermocouple Thermometer

BE 5344

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Introduction

Measuring the temperature plays an important role in detecting potential diseases as some diseases are distinguished by the change in body temperatures. The body temperature at the homeostasis state is 37 ^{o}C. However, if there are intruding factors such as viruses or bacteria, the body will raise its temperature as the defensive mechanism to fight against the intruding viruses and protect the body (3).

Being able to measure temperature is important to everyone in some form or fashion. In a medical setting, being able to accurately detect temperature will affect medical decision making (diagnosis, testing, therapies). Temperature in a medical setting is mostly taken via infrared thermometers or digital thermometers (orally, axillary) (5). Other specific methods involve tympanic thermocouples, nasopharyngeal probes, and pulmonary artery thermistors (6). These other methods are more invasive, so the digital thermometer is the standard practice.

Digital thermometers are devices that have a temperature sensor that converts thermal energy into a numerical value that can be interpreted by the user. Figure 14 in Appendix A shows a diagram of a basic digital thermometer. There are 2 main types of temperature sensors commonly used in digital thermometers: thermistors and thermocouples. Thermistors work by a variation of resistance (2). A change in temperature will cause a change in resistance. If the thermistor has a negative coefficient, a decrease in temperature will cause a decrease in resistance (1). Similarly, with a positive coefficient, an increase in temperature will cause an increase in resistance. (Alan, 2021) Thermocouple sensors have 2 metal wires made of different metals. The voltage between the two metals will change depending on the temperature (4). Both of these sensors have their pros and cons that must be evaluated when deciding between them to make a thermometer.

In this project, we will build a circuit with a thermocouple sensor to make a thermometer. With the circuit built, we will then learn to calibrate it to accurately record temperature. Using the oscilloscope, we will observe the system response, gain and SNR and record the data for further filtering and analysis.

Methods and Materials

Materials:

The following components were used to build and test the system for the project:

Figure 1. Mercury thermometer used to record temperature for calibration points.

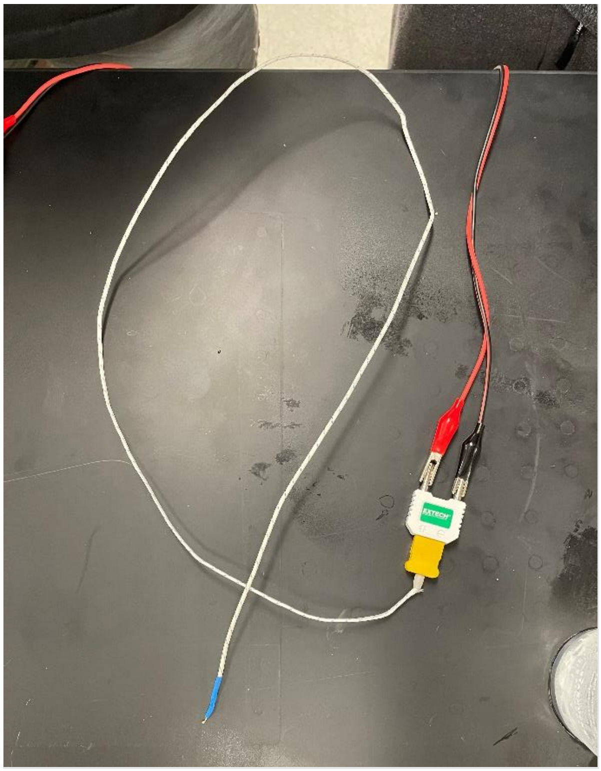


Figure 2. Thermocouple serves as a temperature sensor that converts temperature changes to equivalent voltage changes.

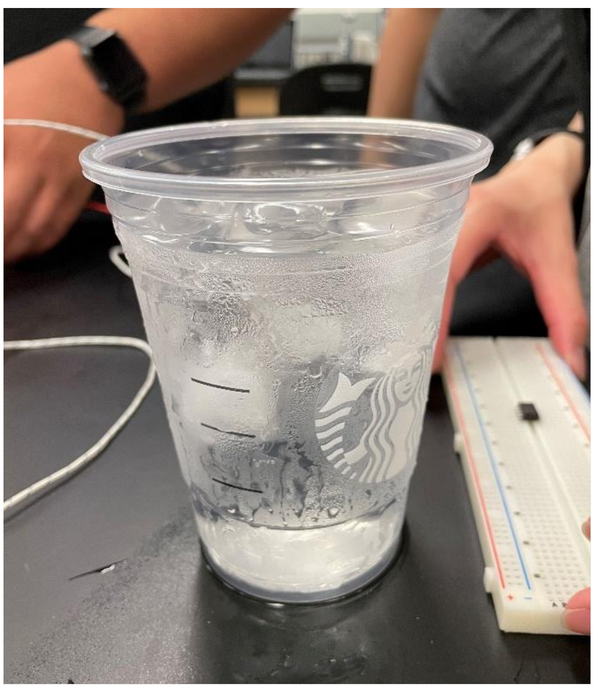


Figure 3. Iced water at 6°C is used as one of two temperature references for calibrating the system.

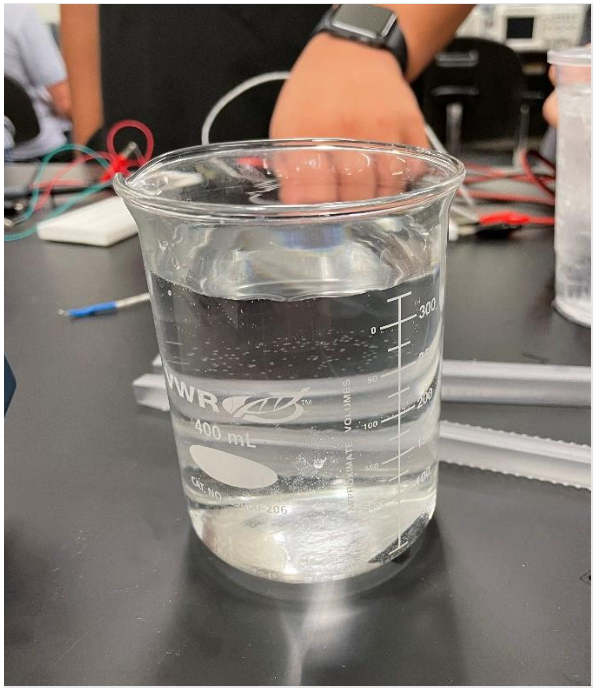


Figure 4. Hot water at 36℃ is used as one of two temperature references for calibrating the system.

Figure 5. Oscilloscope used to visualize and record the data.

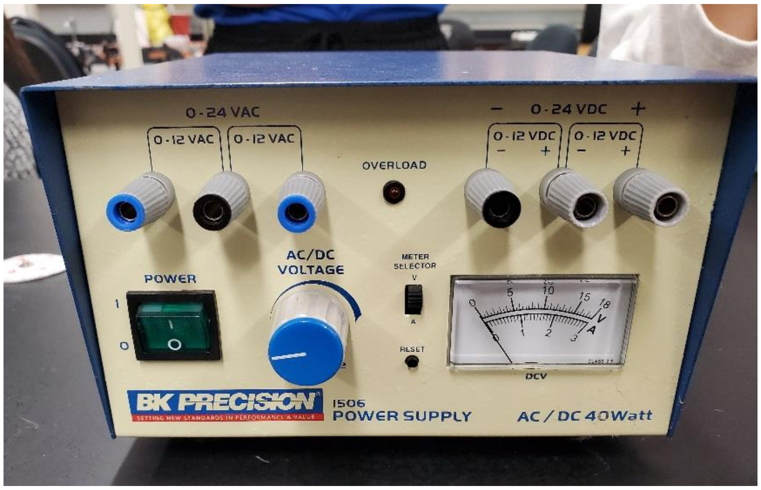


Figure 6. Voltage source used to power the data acquisition circuit.

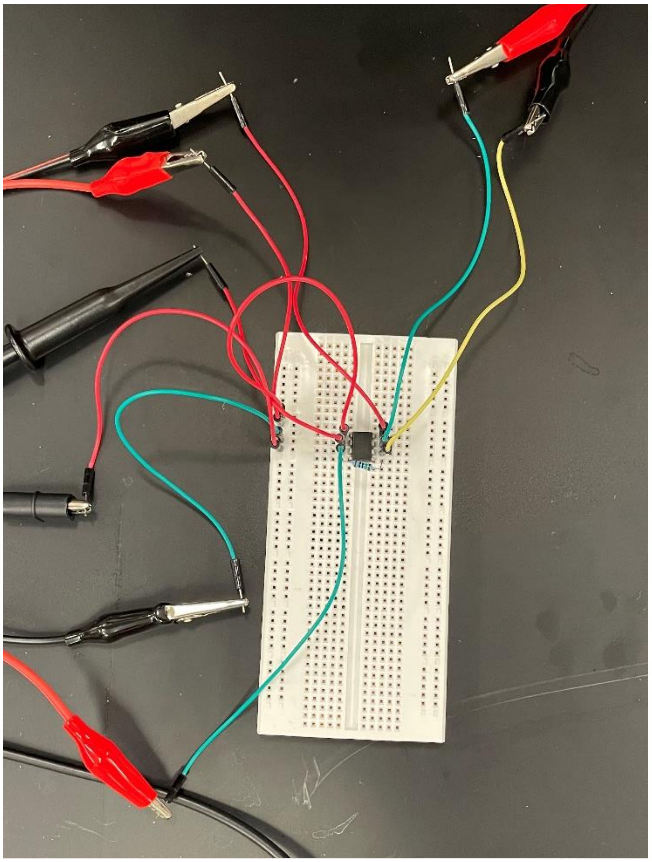
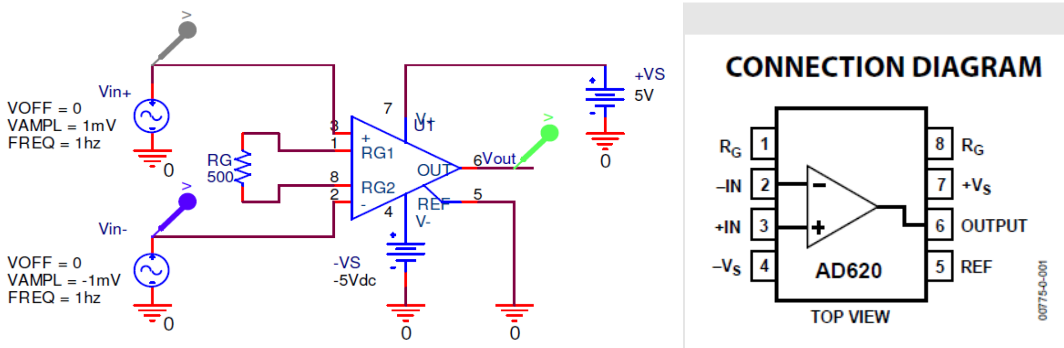


Figure 7. Data acquisition circuit consisting of a 150Ω resistor, AD620 operational amplifier, breadboard, and jumper wires.

Methods:

The following steps were taken to build and test the system:

1. The data acquisition circuit was constructed based on the schematic and connection diagram below:



(a) (b)

Figure 8. (a) Circuit schematic and (b) connection diagram for the AD620 op-amp.

   a. A 150Ω resistor was placed on the breadboard, connecting pins 1 and 8 of the AD620 op-amp.
   b. Pins 2 and 3 of the op-amp were connected to the negative and positive ends of the thermocouple, respectively.
   c. Two voltage sources supplied +5V and -5V to the circuit at pins 7 and 4 of the op-amp, respectively.
   d. Pin 6 of the op-amp was connected to the oscilloscope to visualize the output signal.
2. To calibrate the measurement system, temperature and voltage data were obtained from two references, hot water and iced water.
   a. The temperature of the hot water was first measured using the mercury thermometer and recorded.
   b. The corresponding voltage value of the hot water was obtained using the acquisition circuit. The thermocouple probe was left to sit in the hot water for a few minutes to record the signal on the oscilloscope.
   c. The thermocouple probe was then removed from the hot water and placed into the iced water. Steps 2a and 2b were repeated for the iced water, using the mercury thermometer to record its temperature, the thermocouple to measure the corresponding voltage value, and the oscilloscope to record the output voltage signal.
   d. The data obtained from the two references were used to establish a calibration curve and determine the relationship between the temperature and voltage values.
   e. The calibration data was recorded and analyzed as Experiment 1.
3. The acquisition circuit was then used to obtain voltage data corresponding with body temperature.
   a. The thermocouple probe was first placed in the iced water as a starting reference point.
   b. A subject then removed the probe from the water and pinched it with their fingers. The resulting signal was recorded on the oscilloscope after stabilizing.
   c. This step was repeated to acquire a total of 3 data sets for body temperature.
   d. The testing data was recorded and analyzed as Experiment 2, Experiment 3, and Experiment 4.

4. A digital filter was used to filter all the data to get clean signals for data analysis (see Appendix B for the code).

Results

Recorded data was filtered using Matlab code found in Appendix B and the following results were obtained for four experiment data that was recorded:

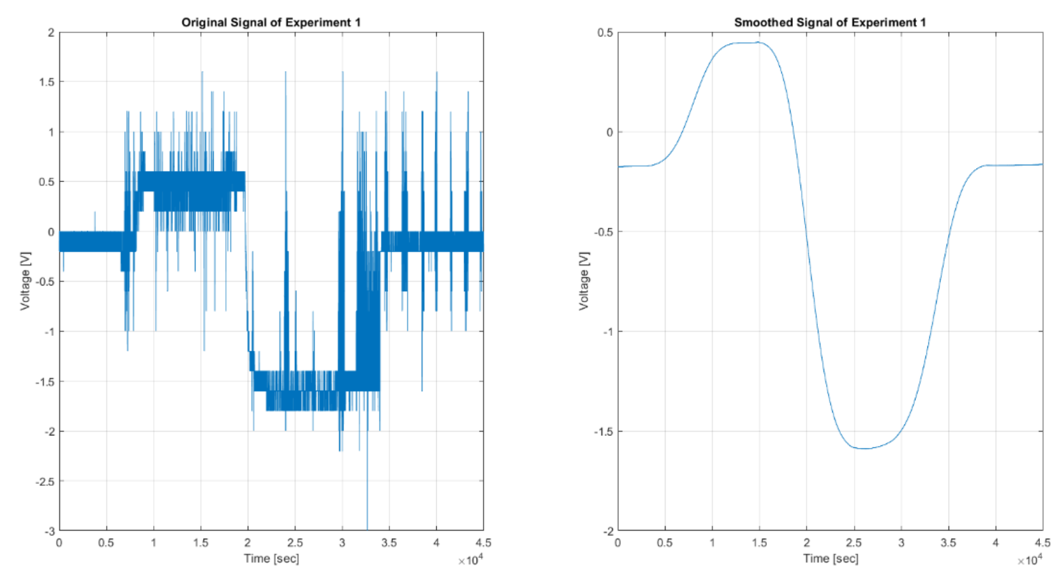


Figure 9. Representation of original and smoothed out signal of Experiment 1.

According to the data from Experiment 1, the measured voltage is 0.44 V at 36℃ and -1.58 V at 6℃ (Figure 9). Hence, the linear calibration curve was generated to show the relationship between Voltage (V) and Temperature (°C) (Figure 10).

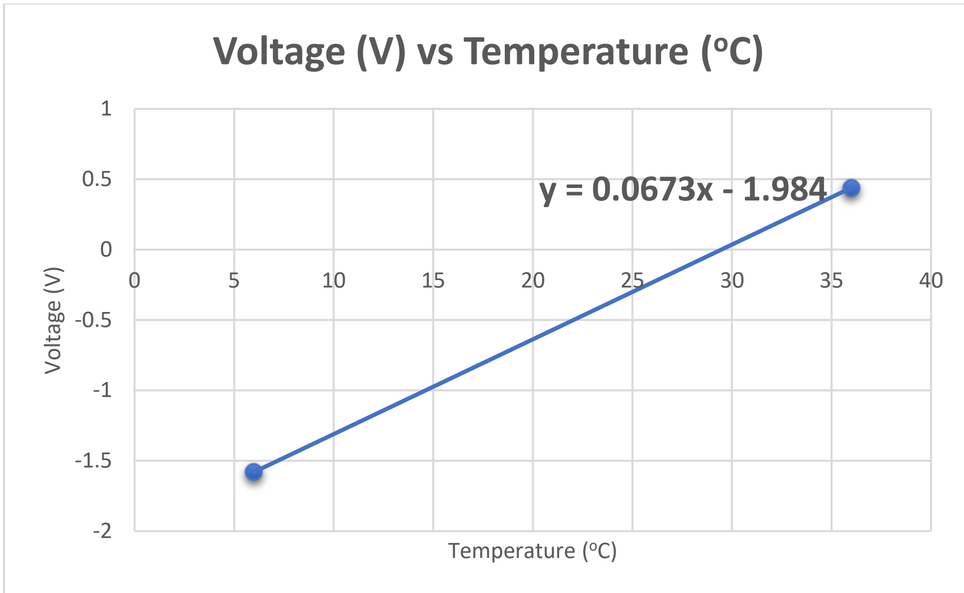


Figure 10. Linear calibration curve generated using data from Experiment 1 showing relationship between voltage and temperature.

After calibrating the system, the voltage values corresponding with body temperature were measured repeatedly through Experiments 2 to 4.

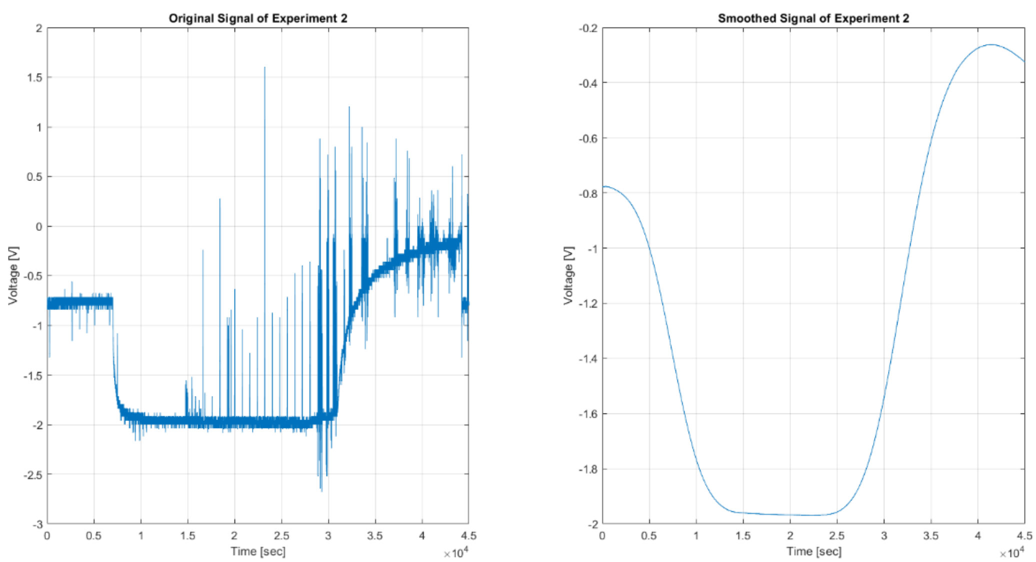


Figure 11. Representation of original and smoothed out signal of Experiment 2.

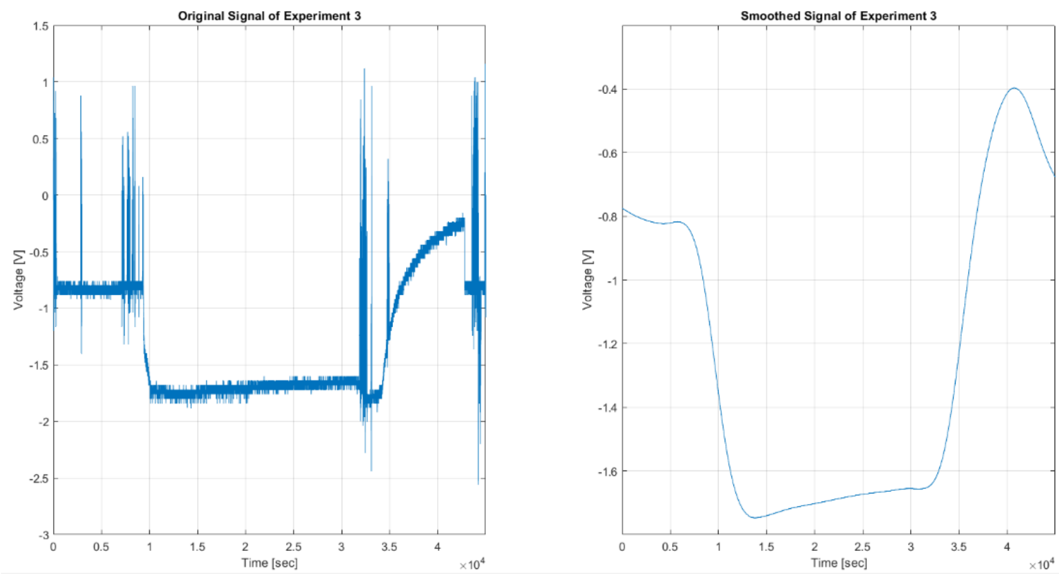


Figure 12. Representation of original and smoothed out signal of Experiment 3.

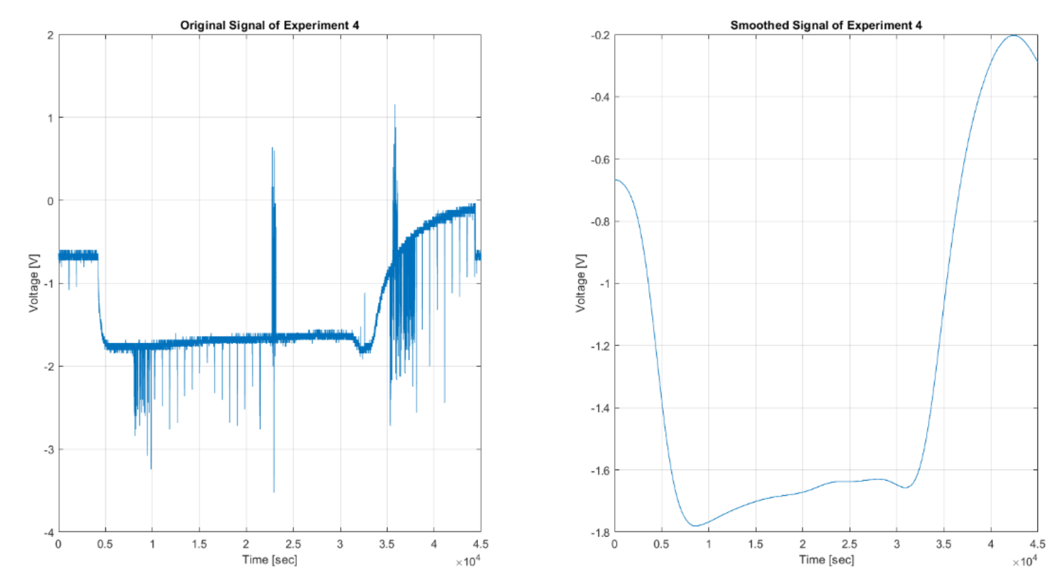


Figure 13. Representation of original and smoothed out signal of Experiment 4.

From Figure 10, the body temperature was calculated from each of the three experiments using Equation 1 and recorded in Table 1.

$$\boldsymbol{y = 0.0673x - 1.984} \qquad (1)$$

y *is the voltage calculated* **in Volts**
x *is the body temperature* **in °C**

$$\boldsymbol{\delta = \left|\frac{(vA - vE)}{vE}\right| \cdot 100\%}$$

δ *is the relative error* **(%)**

vA *is the observed value*

vE *is the expected value*

Table 1. Voltage vs. Response Time and calculated Body Temperature with Relative Error

Experiment	Response time (s)	Voltage (V)	Body temperature (℃)	Relative error (%)
2	5.00	-0.25	25.77	30.36
3	4.00	-0.40	23.54	36.39
4	4.50	-0.20	26.51	28.36
Average	**4.50**	**-0.28**	**25.27**	**31.70**

Discussion

In this project, the thermocouple was used as the transducer to convert body temperature (thermal energy) into a voltage. The change in temperature of the two metals in the thermocouple caused a voltage difference. This voltage was passed through a non-inverting op-amp to amplify the incoming signal by amplifying and outputting the voltage difference between the two input pins of the op amp. Since a non-inverting op-amp was being used, the gain would always be larger than 1. The increase in gain is dependent on the resistor used. A 150 Ω resistor was used which resulted in a gain of 330. This resistor was used since smaller resistors were resulting in excess noise and larger resistors did not provide an adequate signal.

We conducted 4 experiments for project 2. Experiment 1 consisted of calibrating the thermometer which was necessary to provide a reference point when calculating the unknown body temperature and ensuring accurate readings. From figure 9, the measured voltage is 0.44 V at 36 ℃ and -1.58 V at 6 ℃. The linear calibration curve and equation was generated to show the relationship between Voltage (V) and Temperature (℃). There is a positive relationship between voltage and temperature, specifically, as temperature increased, the voltage increased. The calibration curve and equation then are applied to find the unknown body temperature based on the voltage measurements in the next three experiments.

According to the data on Table 1, the average body temperature measured was 25.27 ℃. Comparing to the normal body temperature (37 ℃), the calculated body temperature from the system is less than the expected valued, with a relative error of 31.70%. The difference between these values suggests that there are reasonable for the present of errors for different sources. First, not all parts of the body can provide an accurate reading. Specifically, rectal temperatures are considered the most accurate indication of the body's temperature. Oral and axillary temperature readings are about 0.3°C to 0.6°C below rectal. Temperatures taken from the armpit are usually the least accurate. In this experiment, the fingertip is used to measure the body temperature; therefore, the recorded temperature will be lower than the predicted value. In addition, a thermocouple measures temperature differentials, so any temperature fluctuations around the reference junction can result in an erroneous temperature reading.

Conclusion

In conclusion, the higher the voltage measured, the higher the resulting body temperature. Even though there are differences in the voltages produced, the difference in response time was not significant. Aside from that, although experiments 2 to 4 are conducted with the same procedure, the collected results are still having slight differences compared to each other. The differences in the data could be due to the speed of data collection and the surrounding temperature could affect the measurement. Therefore, it can be concluded that in a confined and stable temperature environment, the collected data will have small relative errors compared to the normal human body temperature. By conducting experiments in the environment that have plenty of unstable and uncontrollable factors, the collected data may produce the undesirable results with a considerable number of errors within them.

References

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[7] Baura, Gail. (2021). Chapter 12 Thermometers. Medical Device Technologies: A System Based Overview Using Engineering Standards. (3rd ed, pp 305-325)

Appendix A

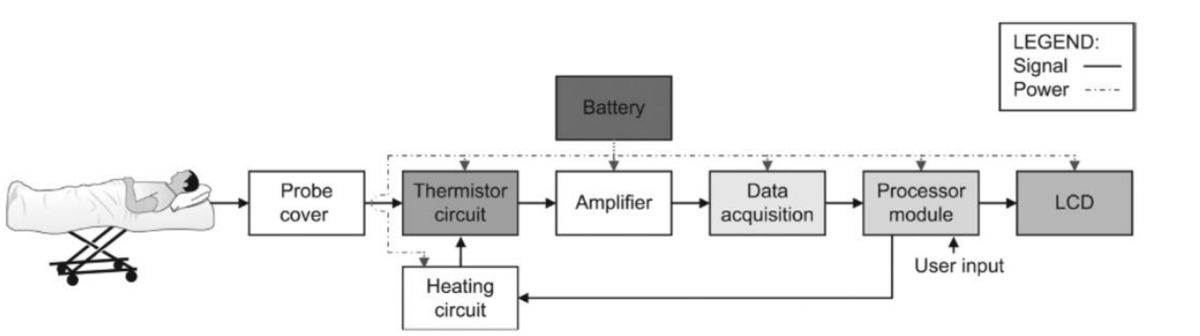

Figure 14. Diagram of basic digital thermometer. [7]

Appendix B

```
%Matlab code
clear;clc;close all

%Initializing
A=readmatrix('BK000006.csv');
Time=A(:,1);
Voltage=A(:,2);
%% Original signal
plot(Time,Voltage),title('Original Signal of Experiment 5')
xlabel("Time [sec]")
ylabel("Voltage [V]")
grid on

%Generate frequency magnitude spectrum using FFT
fs = 50000; %sampling frequency (Hz)
L = length(A); %length of signal (# of samples)
y = fft(A);
ds = abs(y/L); %double-sided amplitude spectrum (w/ normalized amplitudes to match power of
time-domain signal)
ss = ds(1:(L/2)+1); %single-sided amplitude spectrum
%fft divides total input power in 1/2 b/w +/- frequency values, hence . . .
ss(2:end-1) = 2*ss(2:end-1); %doubles amplitudes to compensate for missing (-) values and get
total amplitude
f = (0: L/2)*fs/L; %converts freq axis from freq bins to Hz
figure

%Signal Processing
B=lowpass(Voltage,1,fs);
figure

%% Smoothed curve
```

```
figure
C=smoothdata(B,'gaussian').
figure
D=smoothdata(Voltage,'gaussian').
plot(Time,D),title('Smoothed Signal of Experiment 5')
xlabel("Time [sec]")
ylabel("Voltage [V]")
grid on
```