University of New Haven

Department of Mechanical Engineering

To: Dr. Dieckman September 28, 2022

From: Semih Akyuz, Raymond Pagan Jr.

Re: Temperature Readings of Thermistor and Amplified Thermocouple in Comparison to Reference Readings

Voltage readings were collected from a thermistor, thermocouple, and a temperature sensor submerged in water through varying temperatures. The three sensors were placed into initially hot water and ice was added over time. Thermistor readings followed closely to reference values with a 1.1% difference in slope and an offset of 0.318 ± 0.991 °C [95%]. Thermocouple readings maintained a similar slope with a 2% difference but showed a considerable offset of 15 ± 1.0 °C [95%]. It is predicted that the amplifier used for the thermocouple was operating consistently outside of expected error margins, leading to inaccurate but precise readings. Lines of best fit for calculated temperature readings from the thermistor and thermocouple are shown in Figure 1.

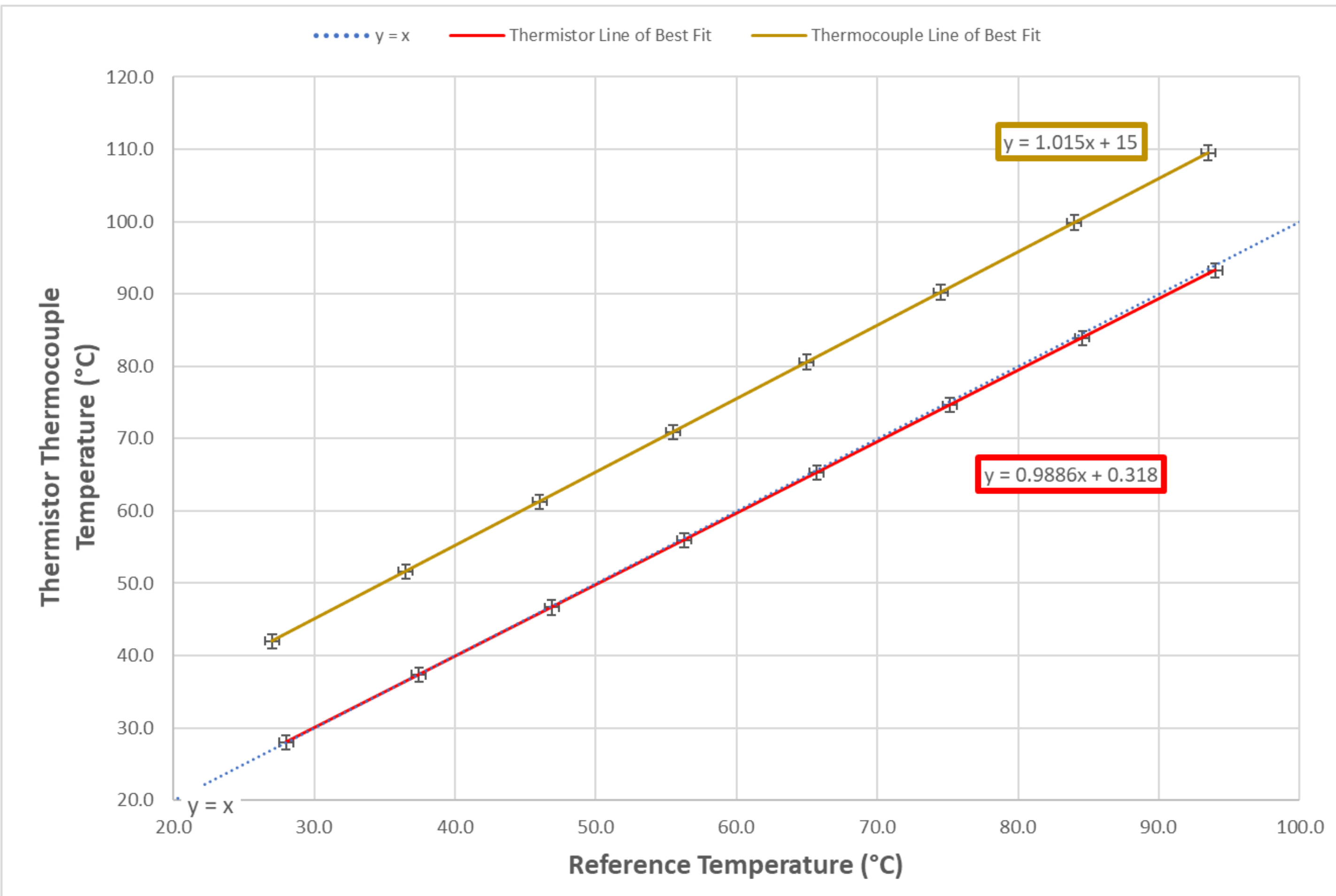

Figure 1. The thermistor follows expected temperatures shown by the line y = x within 1.1% with a minimal offset of 0.318 ± 0.991 °C [95%], while the thermocouple follows within 2% but with a considerable offset of 15 ± 1.0 °C [95%].

Voltage readings from the thermistor and type-k thermocouple were collected through a circuit wired on an ELVIS II board shown in the experimental setup attachment. An AD8495 precision amplifier was used to amplify the outputs of the thermocouple. The analog outputs were collected through LabVIEW, shown in the experimental setup attachment, at a sample rate of 200 samples per second and a sample count of 100 resulting in one reading per half second. Calibration lines of a thermistor and type-k thermocouple were found through a dividing circuit connected to analog outputs of an ELVIS II board. The data was saved to a text file.

Hot water from an electric kettle at ~95 °C was poured into a plastic beaker. The reference probe, thermistor, and thermocouple were placed in the water. After allowing the probes to equalize the data collection process was started in LabView. Ice cubes were dropped into the beaker with a time increment of ~5 seconds for 5 minutes. The voltage to temperature conversion equation provided in the user manual for the AD8495 amplifier was used to calculate temperature in °C where V_{Otc} is the voltage output of the thermocouple [1].

$$Thermocouple_{^\circ C} = (V_{O_{tc}} - 1.25\ )/0.005 \tag{1}$$

The resistance values for the thermistor were calculated using the equation for a voltage dividing circuit with the known resistor R_c, where V_s is the supply voltage and V_{Otm} is the voltage output of the thermistor [2].

$$R_t = \left(\frac{V_s * R_c}{V_{O_{tm}}}\right) - R_c \tag{2}$$

The resistance values of the thermistor were then used in the equation provided by the user manual to calculate the temperature in °C with provided coefficients of $k_0 = 1.02119\ x\ 10^{-3}$, $k_1 = 2.22468\ x\ 10^{-4}$, and $k_2 = 1.33342\ x\ 10^{-7}$ [2].

$$Thermistor_{^\circ C} = [k_0 +\ k_1(\ln 1000R_t) + k_2(\ln 1000R_t)^2]^{-1} - 273.15 \tag{3}$$

Total uncertainty was calculated at a 95% confidence interval using formulas shown in the uncertainty attachment. Calculated temperature readings in °C for the thermistor and thermocouple were plotted against the reference temperatures provided by the vernier temperature probe. Lines of best fit were found for the thermistor and thermocouple readings which were then compared to the expected line $y = x$ with the percent difference.

Findings showed that the best fit line for the thermistor followed expected values of the $y = x$ line closely with a percent difference error in slope *m* by 1.1% and an offset error of 0.318 ± 0.991 °C [95%]. The thermocouple line of best fit followed the expected line closely in slope *m* with a percent difference error of 2% but with a considerable offset of 15 ± 1.0 °C [95%].

Attachments: Calculations, Uncertainty Attachment, Experimental Setup.

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[1] Analog Devices, “Precision Thermocouple Amplifiers with Cold Junction Compensation – AD849x”

[2] Vernier, “Stainless Steel Temperature Probe”, p.2

CALCULATIONS

Thermocouple - Volts to Temperature (°C) [1]

$$\boldsymbol{Thermocouple}_{\circ\boldsymbol{C}} = (V_{O_{tc}} - 1.25)/0.005$$

where

V_{Otc} is the voltage reading from the thermocouple

Thermistor – Resistance (Ω) [2]

$$\boldsymbol{R_t} = \left(\frac{V_s * R_c}{V_{O_{tm}}}\right) - R_c$$

where

V_s is the voltage provided to the dividing circuit

R_c is the constant resistance of the resistor that V_{Otm} is measured across

V_{Otm} is the voltage measured across R_c

Thermistor - Temperature (°C) [2]

$$\boldsymbol{Thermistor}_{\circ\boldsymbol{C}} = [k_0 + k_1(\ln 1000R_t) + k_2(\ln 1000R_t)^2]^{-1} - 273.15$$

where

$k_0 = 1.02119\ x\ 10^{-3}$

$k_1 = 2.22468\ x\ 10^{-4}$

$k_2 = 1.33342\ x\ 10^{-7}$

Slope Percent Difference

$$\%\ \boldsymbol{Diff} = \frac{m_2 - m_1}{m_1} * 100\%$$

where

m_2 is the slope of the line of best fit for temperatures calculated from thermistor and thermocouple readings

m_1 is the slope of the reference line $y = x$

UNCERTAINTY ATTACHMENT

Standard Deviation - (Population)

$$\boldsymbol{\sigma} = \sqrt{\frac{\sum(\boldsymbol{x_i} - \overline{\boldsymbol{x}})^2}{\boldsymbol{N}}}$$

where

x_i is each temperature value in individual data sets from the three sensors

$\overline{x}$ is the mean of each associated data set

N is the number of data points in each data set

Standard Error of the Mean

$$\boldsymbol{\sigma_M} = \frac{\boldsymbol{\sigma}}{\sqrt{\boldsymbol{N}}}$$

where

σ is the standard deviation

N is the number of data points

Uncertainty - Precision

$$\boldsymbol{U_{xP}} = \frac{\boldsymbol{Z} * \boldsymbol{\sigma_M}}{\sqrt{\boldsymbol{N}}}$$

where

Z is the z-score used for the desired confidence interval (1.96 for 95% CI)

σ_M is the standard error of the data set

N is the number of data points in each data set

Uncertainty - Combined

$$\boldsymbol{U_x} = \sqrt{\boldsymbol{u_{xB}^2} + \boldsymbol{u_{xP}^2}}$$

where

U_{xB} is the bias uncertainty of each measurement device provided in associated documentation

U_{xP} is the precision uncertainty

Minimum Slope of Line - (Using Total Uncertainty of Each Axis)

$$\boldsymbol{m_{min} = \frac{Y_{2L} - Y_{1H}}{X_{2H} - X_{1L}}}$$

where

Y_{2L} is the maximum Y value of the line minus the total uncertainty on the Y axis

Y_{1H} is the minimum Y value of the line plus the total uncertainty on the Y axis

X_{2H} is the maximum X value of the line plus the total uncertainty on the X axis

X_{1L} is the minimum X value of the line minus the total uncertainty on the X axis

Maximum Slope of Line – (Using Total Uncertainty of Each Axis)

$$\boldsymbol{m_{max} = \frac{Y_{2H} - Y_{1L}}{X_{2L} - X_{1H}}}$$

where

Y_{2H} is the maximum Y value of the line plus the total uncertainty on the Y axis

Y_{1L} is the minimum Y value of the line minus the total uncertainty on the Y axis

X_{2L} is the maximum X value of the line minus the total uncertainty on the X axis

X_{1H} is the minimum X value of the line plus the total uncertainty on the X axis

Uncertainty of Slope

$$\boldsymbol{U_s = \frac{m_{max} + m_{min}}{2}}$$

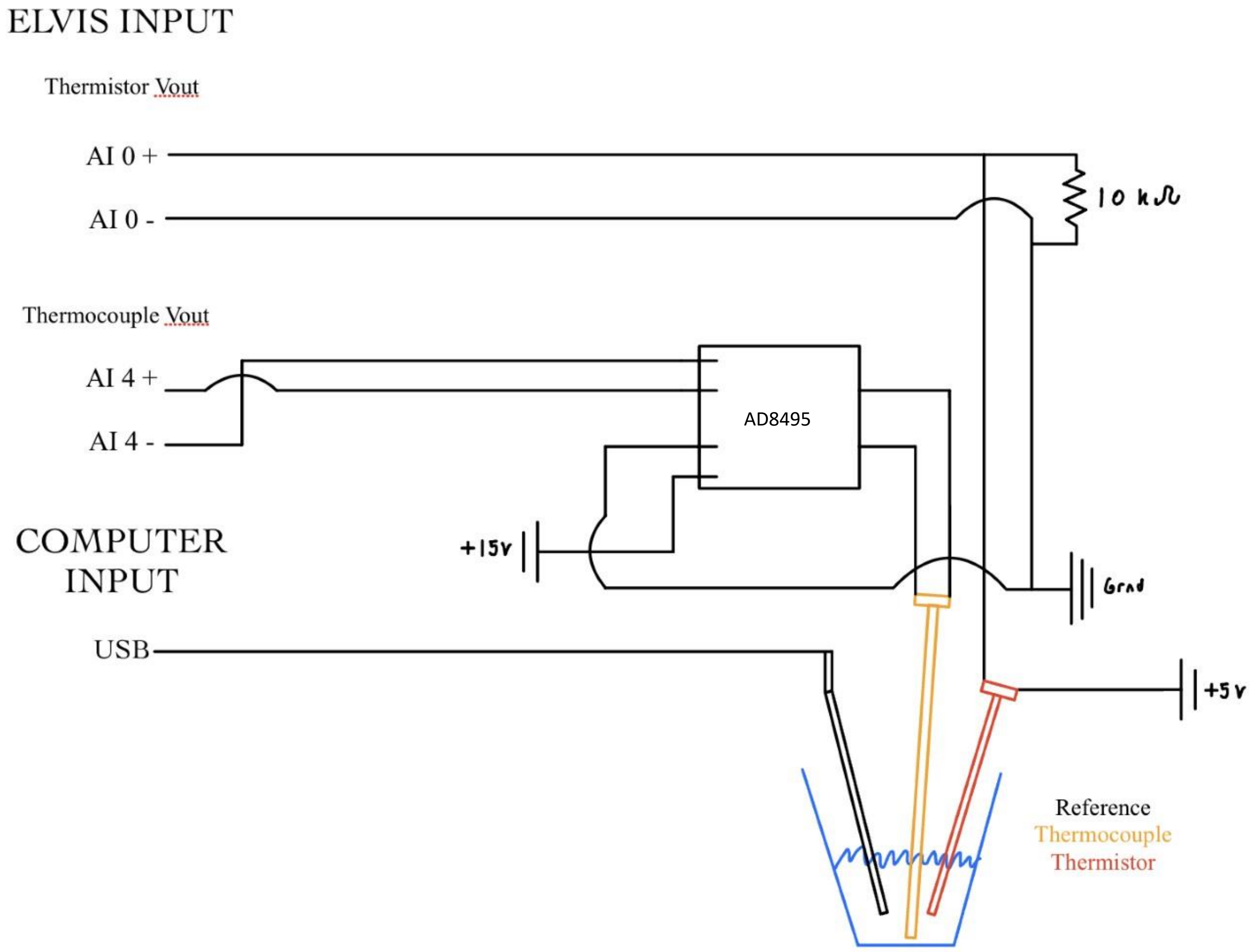
where

m_{max} is the maximum slope of the point set

m_{min} is the minimum slope of the point set

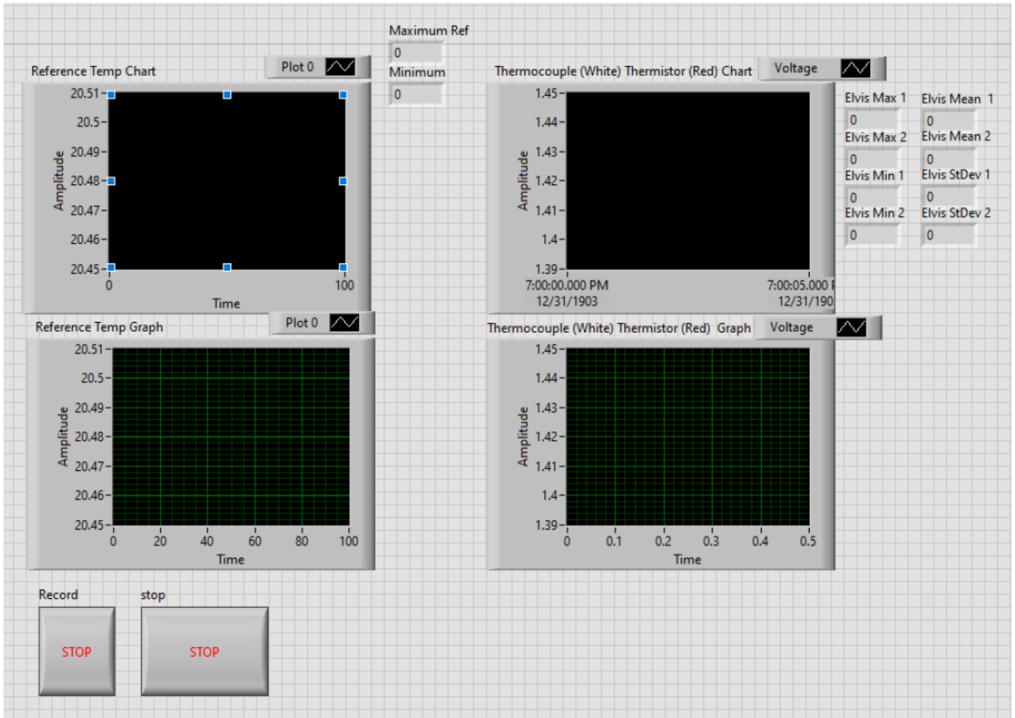
EXPERIMENTAL SETUP

Circuit Diagram



LabVIEW Setup

Front Panel



Block Diagram