NC STATE UNIVERSITY

College of Engineering

Department of Mechanical and Aerospace Engineering

MAE-305, Section 205

Instrumentation and Solid Mechanics Laboratory

Experiment 8

Temperature Measurements

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Abstract

[Primary Contributor: David Delgado]

The objective of this experiment was to become familiar with three methods for obtaining surface temperature measurements of a thermal plant. In addition to learning how to use different temperature measurement tools (i.e., infrared camera, thermistor and thermocouple), students compared the accuracy of each tool based on percent difference calculations. From the three devices, the IR camera was found to be the most accurate due to it having the lowest mean percent difference values when compared to the other methods (8.46%, 47.84%). The percent differences at twenty different time intervals for each individual method can be seen in Table 3. Meanwhile, the thermocouple was the least accurate tool as it had the highest mean percent difference values (47.84%, 55.75%) for all its acquired measurements. Furthermore, it was found that the thermistor had a similar level of accuracy compared to the IR camera, having 8.46% and 55.75% as its mean percent difference values. Hence, future trials of this experiment would benefit not only from enhanced calibration of the equipment (esp. the thermocouple circuit) and taking an average of the readings via LabView for the thermocouple, but also applying Chauvenet's Criterion to eliminate bad data points in the dataset arising from poor experimentation to achieve a better analysis of the percent difference calculations.

1. Introduction

[Primary Contributors: Hannah Fletcher and David Delgado]

The purpose of the experiment was to measure the temperature of an adjustable AC light fixture over a twenty-minute period using three measurement methods, and to compare the accuracy and precision of these methods. Additionally, the lab promoted knowledge of the LabView software and myRIO hardware for data acquisition purposes while experimentally demonstrating the relationship between resistance and temperature, as well as thermocouple principles. In summary, the tasks associated with this lab included:

1. Comparing three methods for measuring the surface temperature of a thermal place: a) using an IR camera, b) using a thermistor, and c) using a thermocouple circuit.
2. Summarizing the experimental methods, results, and comparing the accuracy of temperature measurements in a formal report.

2. Experimental Methods

[Primary Contributor: Hannah Fletcher; Secondary Contributors: Sunghyun Shin, Leena Vo]

List of Items Used

1. Two feet type T thermocouple wire
2. Wire cutters
3. Soldering iron, solder
4. Multimeter with alligator clips (Tektronix DMM4020 5-½ Digit Multimeter)
5. Cup of ice water at 0°C
6. Masking Tape
7. Breadboard (JAMECO Breadboard JE25)
8. NI myRIO
9. Jumper wires
10. 10 kΩ thermistor
11. 10 kΩ resistor
12. 0.1 μF capacitor
13. FLIR camera (Fluke VT04A Visual IR thermometer)
14. Computer with program ThermistorDemo.lvproj

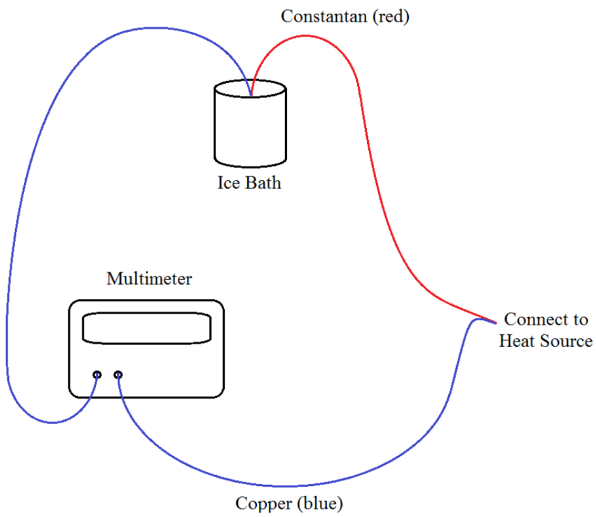

Figure 1, Experiment Setup: The setup involves three components: the ice bath, the multimeter, and the heat source (AC light fixture). The copper wires are attached to the multimeter using alligator clips and one of the copper-constantan joints is placed in the ice bath. The other copper-constantan joint is taped to the top of the AC light fixture.

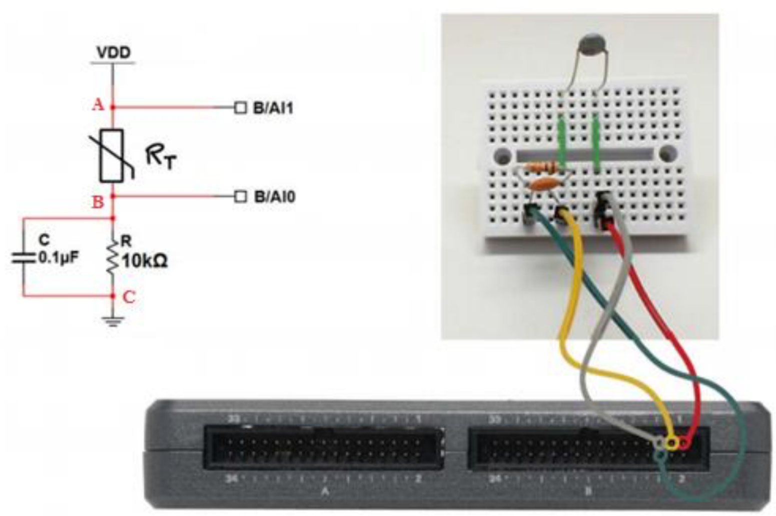

Figure 2, Thermistor Circuit Setup [1]: Circuit diagram shows proper wiring installation. Adapted from *Lab 8: Temperature Measurements Handout* [PDF File], by NC State MAE Department, 2018.

The ends of the copper wire were connected to the multimeter using alligator clips. One of the copper-constantan joints was placed in the ice bath while the other was taped to the top of the AC light source. The resistance of the 10 kΩ thermistor was confirmed using the multimeter. The thermistor setup shown in Figure 2 was connected to the myRIO. The program ThermistorDemo.lvproj was set up on the computer and the FLIR camera was turned on. The AC light was plugged in and turned to maximum brightness. For a duration of 20 minutes every minute the temperature of the top of the light was recorded using all three methods: IR Camera, thermistor, and the thermocouple circuit. Afterwards all lab materials were cleaned up and put away.

3. Experimental Data

[Primary Contributors: David Delgado, Hannah Fletcher, Sunghyun Shin, Leena Vo, Nathan Wang]

Data was collected by recording temperature measurements from the IR camera, voltage measurements from the thermocouple, and resistance measurements from the thermistor.

The IR camera, thermocouple and thermistor provided data that were directly inputted into Table 1. However, only the IR camera provided actual temperature readings. Thus, the data provided by the thermistor and thermocouple were converted to temperature readings by using the following equations:

$$T = [1/((1.1253 \text{ x } 10^{-3}) + (2.3471 \text{ x } 10^{-4})(ln(R)) + (8.5664 \text{ x } 10^{-8})(ln(R))^3)] - 273.15[°C] \quad (1)$$

$$y2 = ((x2-x1)(yb-y1)/(xb-x1)) + y1 \ [°C] \quad (2)$$

Equation 1, also known as the Steinhart-Hart equation, was used to convert the resistance readings from the thermistor to temperatures. In this equation, □ is the thermistor's temperature (°C) and □ is the thermistor's resistance (ohms, Ω). The appendix includes sample conversion calculations used to obtain the values listed in Table 2.

Furthermore, in order to convert the thermocouple column values in millivolts to temperature values, the Conversion Chart for Type T Thermocouples in the lab handout was used. Equation 2, which is a common interpolation equation, was used to estimate the temperature in cases where the exact voltage was not tabulated. In this equation, y2 is the desired temperature reading at the specified voltage reading x2 (mV), yb is the temperature at the upper bound voltage within the chart, xb is the corresponding voltage, yl is the temperature on the lower bound, xl is the corresponding voltage at the lower bound. Sample calculations in the appendix show how the data in Table 2 was obtained.

Table 1, Raw Experimental Data: Recorded measurements from each device each minute.

Time (min)	IR Camera Temp (°C)	Thermocouple V (mV)	Thermistor R (kΩ)
1	26.8	.602	8.95
2	32.2	.719	7.07
3	36.2	.810	5.70

4	38.8	.951	4.87
5	41.2	1.007	4.32
6	43.3	1.044	3.96
7	44.6	1.091	3.70
8	45.5	1.183	3.51
9	46.8	1.192	3.40
10	46.4	1.202	3.29
11	47.2	1.218	3.25
12	49.2	1.254	3.26
13	49.2	1.260	3.17
14	48.6	1.275	3.13
15	50.2	1.152	3.13
16	50.9	1.143	3.12
17	49.8	1.139	3.16
18	48.8	1.249	3.08
19	48.2	1.217	3.07
20	49.2	1.218	3.05

Table 2, Raw Data Celsius Conversion: Conversion of the thermocouple and thermistor values of voltage and resistance into values of temperature (Celsius).

Time (min)	IR Camera Temp (°C)	Thermocouple V (°C)	Thermistor R (°C)
1	26.8	15.325	27.551
2	32.2	18.25	33.098
3	36.2	20.5	38.325
4	38.8	24	42.245

5	41.2	25.366	45.29
6	43.3	26.268	47.534
7	44.6	27.425	49.305
8	45.5	29.683	50.692
9	46.8	29.902	51.535
10	46.4	30.143	52.41
11	47.2	30.524	52.736
12	49.2	31.39	52.654
13	49.2	31.537	53.403
14	48.6	31.902	53.744
15	50.2	28.927	53.744
16	50.9	28.707	53.83
17	49.8	28.61	53.488
18	48.8	31.25	54.177
19	48.2	30.5	54.264
20	49.2	30.524	54.44

4. Theory and Analysis

[Primary Contributors: David Delgado, Hannah Fletcher, and Leena Vo]

In order to compare the accuracies between the three tools, experimental percent differences were calculated using the following equation:

$$\%\, diff = \frac{|Value_{exp} - Value_{pub}|}{\frac{1}{2}(Value_{exp} + Value_{pub})} \times 100\% \tag{3}$$

Where $value_{pub}$ is equal to the temperature acquired at a given time interval for one method and $value_{exp}$ is the temperature recorded for a different method at that same time. The experimental temperature values for $value_{pub}$ and $value_{exp}$ were taken from Table 2.

Table 3, Percent Difference Between Different Methods: Percent differences between the three measurement tools' celsius values were calculated with Equation 3.

Time (min)	IR Camera vs. Thermistor	IR Camera vs. Thermocouple	Thermistor vs. Thermocouple
1	2.7635%	54.4807%	57.0296%
2	2.7505%	55.3023%	57.8328%
3	5.7028%	55.3792%	60.6035%
4	8.5015%	47.1338%	55.0834%
5	9.4577%	47.5738%	56.3972%
6	9.3225%	48.9650%	57.6299%
7	10.0208%	47.6918%	57.0312%
8	10.795%	42.0760%	52.2775%
9	9.6304%	44.0614%	53.1282%
10	12.1647%	42.4781%	53.9460%
11	11.0791%	42.9108%	53.3558%
12	6.7823%	44.1990%	50.6021%
13	8.1927%	43.7544%	51.4858%
14	10.0524%	41.4847%	51.0000%
15	6.8191%	53.7693%	60.0380%
16	5.5953%	55.7564%	60.8769%
17	7.1412%	54.0492%	60.6056%
18	10.4431%	43.8476%	53.6762%
19	11.8364%	44.9809%	56.0710%

20	10.1119%	46.8516%	56.2968%
Mean % diff	**8.4581%**	**47.8373%**	**55.7484%**

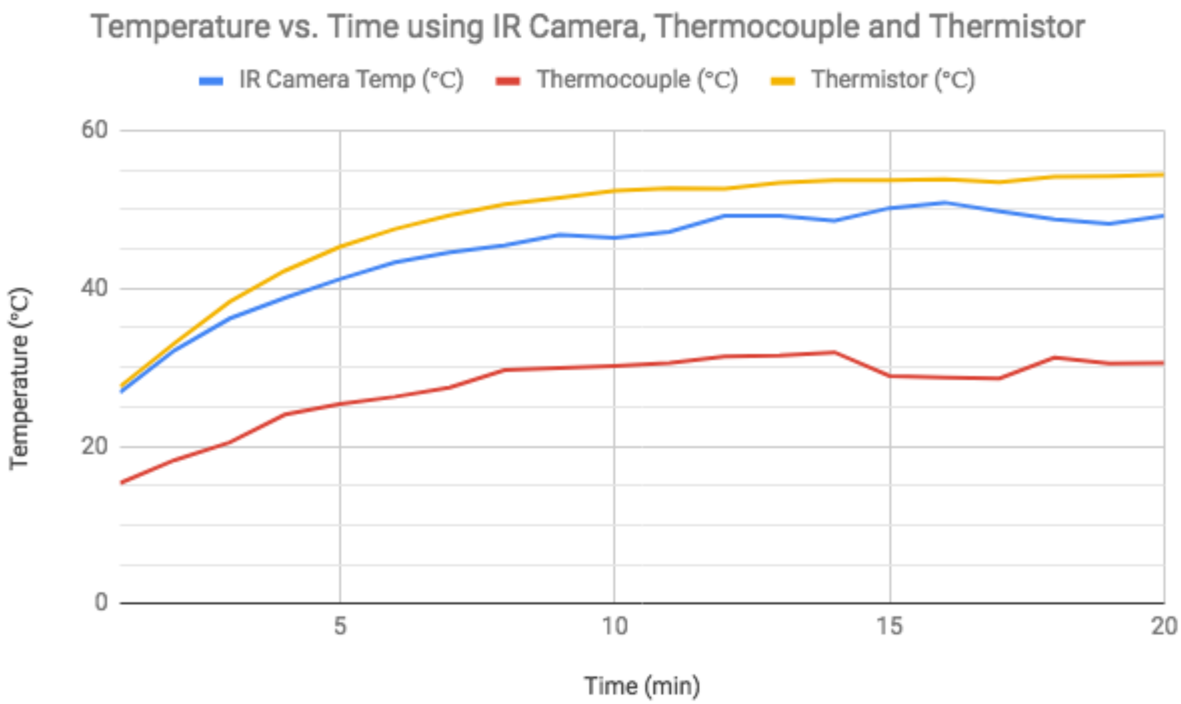

Figure 3, Temperature vs. Time For The Three Measurement Methods: Graph compares the temperature-versus-time relationship between the three tools. All three tools have the same behavior: increasing until 10 mins and then staying constant.

Based on the calculated percent differences in Table 3, it can be concluded that the most accurate tool is the IR camera, and the least accurate tool is the thermocouple. This is due to the fact that the IR camera pertains to the two groups with the lowest mean percent difference values (8.46% and 47.84%) and the thermocouple is in the two groups with the highest values (47.84% and 55.75%). Furthermore, the thermistor is a close contender for the most accurate tool but it produced slightly higher surface temperature values when compared to the thermocouple. However, due to the unreliability of the thermocouple, it would be worthwhile to run the experiment again to obtain more accurate surface temperature readings based on voltage and re-calculate percent differences for all three groups.

Lastly, Figure 3 suggests that the thermistor is the most precise tool, because its line has the least irregularities (i.e. its temperature vs. time relationships follows the smoothest curve). This conclusion aligns with research found online [4] and comments made by Dr. Kribs, indicating the thermistor should be the most accurate source. The IR camera makes many assumptions when calculating heat values due to the different colors of materials. While all three methods have their advantages, this report assumes that the IR camera and the thermistor are the most widely implemented measurement tools. The IR camera is very convenient as it provides instant temperature readings while the thermistor is the most accurate and thus would be the best method when accuracy is important.

5. Discussion

[Primary Contributors: David Delgado, Hannah Fletcher, Nathan Wang]

Thermocouple data was not as consistent as our other methods in recording the temperature of the bulb. Thermocouples have a higher operating temperature range, around 200°C to 1750°C while thermistors typically retain their accuracy from -100°C to 325°C. Since the bulb did not get hotter than 55°C which is inside the ideal range of a thermistor, it makes sense for the thermistor to have the smoothest curve. The IR camera has a temperature range from -10°C to 250°C, which is demonstrated by its accuracy being close to that of the thermistor. The smoothness of the measured temperature curve for each method correlates closely to how precise each instrument is, and is backed by each respective operating temperature range. The skewed thermocouple data may be reassessed by repeating the experiment several times and allowing the bulb to cool down to room temperature between each test.

Possible sources of error may include improper circuit assembly for the thermocouple, causing a differential in temperature measurements. Lack of insulation at the end of the thermocouple may have had an effect on heat transfer rate to surroundings, which potentially skewed the reading temperature. Additionally, the temperatures were recorded within a Furthermore, readings were taken within a 10 second period of each other, but could have been taken in a more timely fashion. Future testings should be run to determine the cause of error for the thermocouple and specifically if the setup was done erroneously in this experiment. The IR camera had some variation in results compared with the thermistor due to the calculation assumptions made by the machine when giving the user a reading.

6. Conclusions

[Primary Contributors: David Delgado, Hannah Fletcher, Sunghyun Shin, Leena Vo, Nathan Wang]

From the results of the percent different analysis it was determined that the IR camera was the most accurate tool for measuring the surface temperature of the thermal plant due to it having the smallest mean percent differences (8.46% and 47.84%), while the thermocouple was the least accurate due to it having the largest mean percent differences (47.84% and 55.75%). All three methods had their merits and downfalls. Even though the thermocouple method had the largest percent difference on average in its measurements when compared to the other two measurement methods, it was able to measure voltage to three decimal places and thus provide a more exact temperature calculation, which the other tools were unable to provide. Using IR camera was incredibly convenient as it provides immediate temperature results with minimal setup; however, it makes assumptions in its calculations regarding the color of the object emitting heat and is therefore less accurate. As long as precision is not the most important factor, industry would prefer IR camera the most due to its convenience.

For the raw data in the t=18 (mins) row, there was a ~20 second delay in recording the values. Thus, the raw data values in that row were a little higher or lower than they should have been which slightly affected Figure 3, Table 2, and Table 3. To reduce future errors, closer attention should be paid when manually obtaining values. In addition, emissivity and absorptivity are assumed by the IR camera, which affects the accuracy of the IR camera. Thus, it is another source of error.

To improve the Figure 3 graph (a more curve-shaped line for the IR camera and thermocouple), the equipment could be better calibrated before taking measurements. The raw data set could also be cleaned up by using Chauvenet's Criterion, which would eliminate "bad" data points due to poor experimentation techniques and result in a more accurate analysis of the percent difference calculations. For further study, an average of the LabView readings for the thermocouple could also be taken. Re-calculating the percent differences in error measurements from the actual surface temperature should be investigated in a future lab experiment, which would require a thermal plan with a built-in temperature indicator.

7. References

[Primary Contributor: Leena Vo]

[1] Doering, Ed. (2013). *NI MyRIO Project Essentials Guide*. N.p.: National Technology and Science.

[2] *Thermocouple Reference Tables Type T.* Omega

[3] NC State MAE Department. (2018). *Lab 8: Temperature Measurements Handout* [PDF File].

[4] "Thermocouple vs Thermistor - Difference between Thermocouple and Thermistor." *YouTube*, Learning Engineering, 11 May 2018, www.youtube.com/watch?v=T6ykoEgWR8Y.

8. Sample Calculations

[Primary Contributor: David Delgado]

Several equations were used to properly conduct the lab. For instance, the Steinhart-Hart Equation was used to convert the resistance readings from the thermistor to temperatures:

$$1/T = a + b(ln(R)) + c(ln(R))^3 [1/\text{K}]$$

Where *T* is the thermistor's temperature (K), *R* is the thermistor's resistance (ohms, Ω) and *a*, *b*, and *c* are Steinhart-Hart parameters which depend on the type of thermistor used. Given that a 10 kΩ resistor was used, the values of these parameters are as follows:

$$a = 1.1253 \text{ x } 10^{-3}, b = 2.3471 \text{ x } 10^{-4}, c = 8.5664 \text{ x } 10^{-8}$$

Hence, the temperatures were acquired in °C using the following equation:

$$T = [1/((1.1253 \text{ x } 10^{-3}) + (2.3471 \text{ x } 10^{-4})(ln(R)) + (8.5664 \text{ x } 10^{-8})(ln(R))^3)] - 273.15[°C] \tag{1}$$

A sample calculation of the experimental surface temperature using the thermistor is shown below. In this example, R = 8.95 kΩ at time t = 1 minute:

$$\boldsymbol{T} = [\mathbf{1}/((\mathbf{1.1253} \text{ x } \mathbf{10^{-3}}) + (\mathbf{2.3471} \text{ x } \mathbf{10^{-4}})(\boldsymbol{ln}(\mathbf{8950}\boldsymbol{\Omega})) + (\mathbf{8.5664} \text{ x } \mathbf{10^{-8}})(\boldsymbol{ln}(\mathbf{8950}\boldsymbol{\Omega}))^{\mathbf{3}})] - \mathbf{273.15}$$

$$\boldsymbol{T} = 27.551°C$$

Thermocouple conversion charts were used to accurately convert measured voltage values to corresponding temperature values. In this case, a 0 $°C$ reference temperature and a copper-constantan (Type T) thermocouple wire were used. However, there were some instances where interpolation was required since the exact voltage readings in millivolts was not always tabulated. In these cases, the following equation was used to interpolate a surface temperature:

(y2-y1)/(x2-x1) = (yb-y1)/(xb-x1)

y2 = ((x2-x1)(yb-y1)/(xb-x1)) + y1 [°C] (2)

Where y2 is the desired temperature reading at the specified voltage reading x2 (mV), yb is the temperature at the upper bound voltage within the chart, xb is the corresponding voltage, yl is the temperature on the lower bound, xl is the corresponding voltage at the lower bound. An example calculation for the first voltage reading at time t = 1 minute is shown below:

y2 = ((0.602-0.589)(16-15)/(0.629-0.589)) + 15 °C

T = y2 = 15.325 °C

Lastly, percent differences were calculated between the three measurement methods using the following equation:

$$\%\, diff = \frac{|Value_{exp} - Value_{pub}|}{\frac{1}{2}(Value_{exp} + Value_{pub})} \times 100\% \tag{3}$$

Where $value_{pub}$ is equal to the temperature acquired at a given time interval for one method and $value_{exp}$ is the temperature recorded for a different method at that same time. The experimental percent difference values for IR camera vs. thermocouple, IR camera vs. thermistor, and thermocouple vs. thermistor are show in Table 3. A sample calculation for percent difference between the IR camera and thermistor temperatures at time t = 1 minute is show below:

$$\% \, diff = [|27.551 - 26.8| \, / \, ((27.551 + 26.8)/2)] \text{ x } 100\% = 2.7635\%$$