Calibration Report: Telemetry 5
MEAM 2480 Lab0

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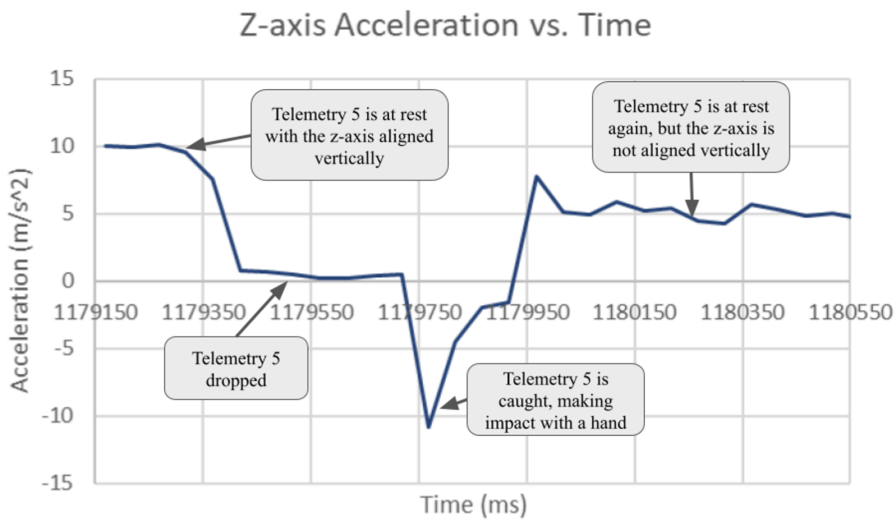
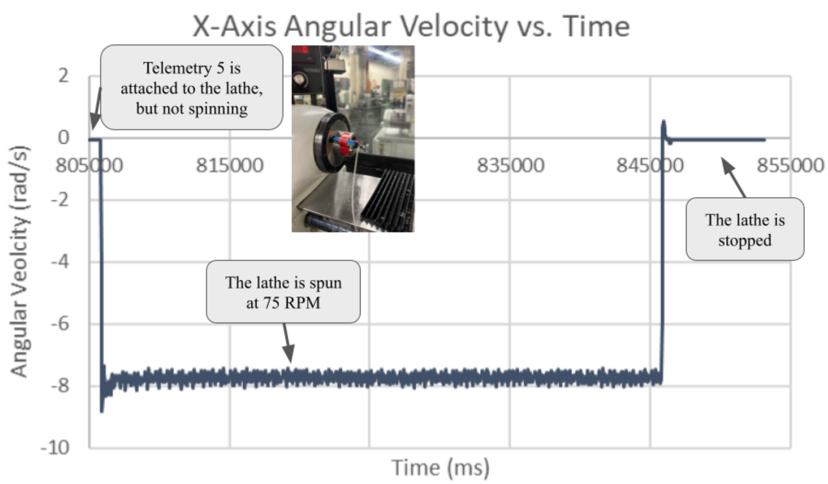
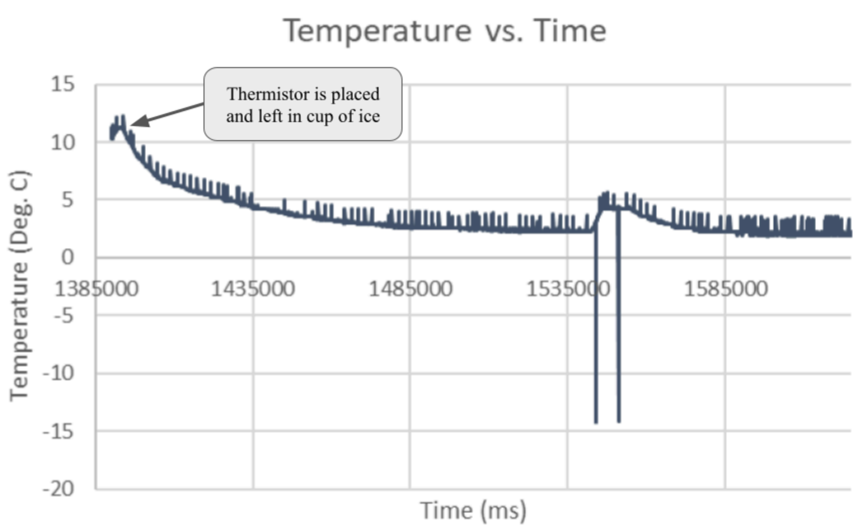
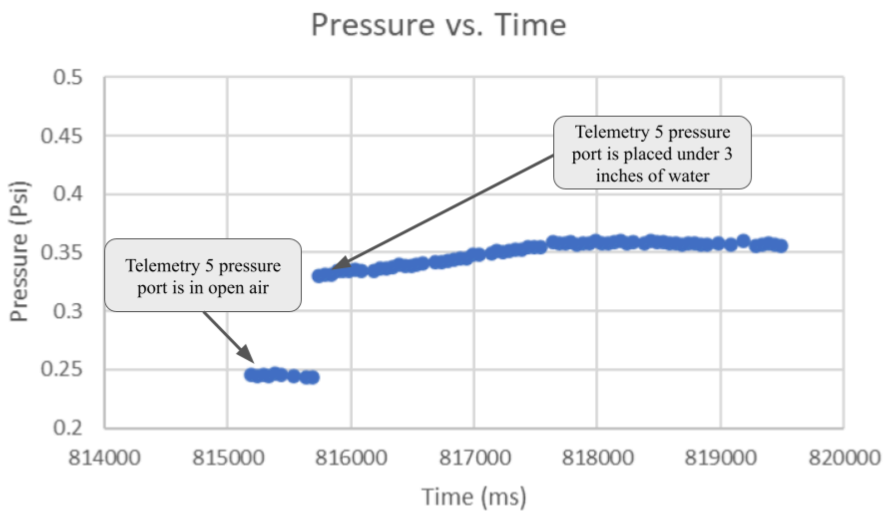
1. Plotting Sensor Data vs. Time



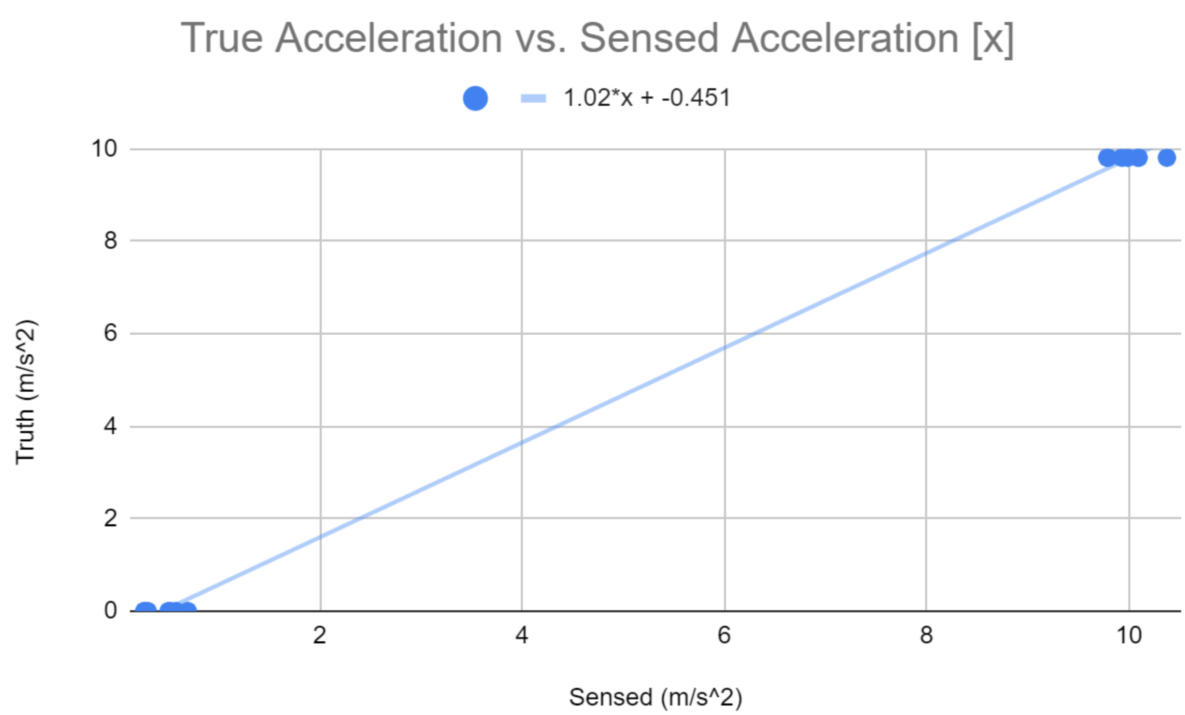





Pressure vs. Time
Pressure (Psi)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
814000
815000
816000
817000
818000
819000
820000
Time (ms)
Telemetry 5 pressure port is placed under 3 inches of water
Telemetry 5 pressure port is in open air

2. **Individual Measurement Calibration (including equations and methods)**

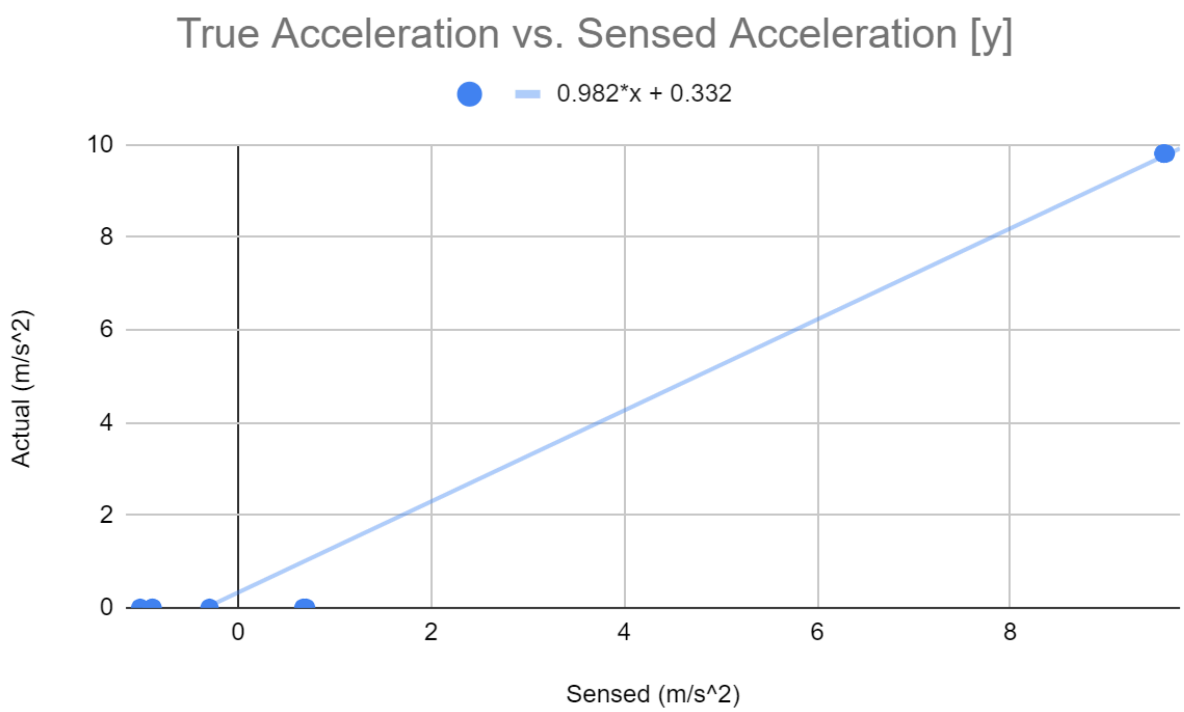
2a. Calibrating X-Acceleration



Equation: $Actual = 1.02(Sensed) - 0.451$

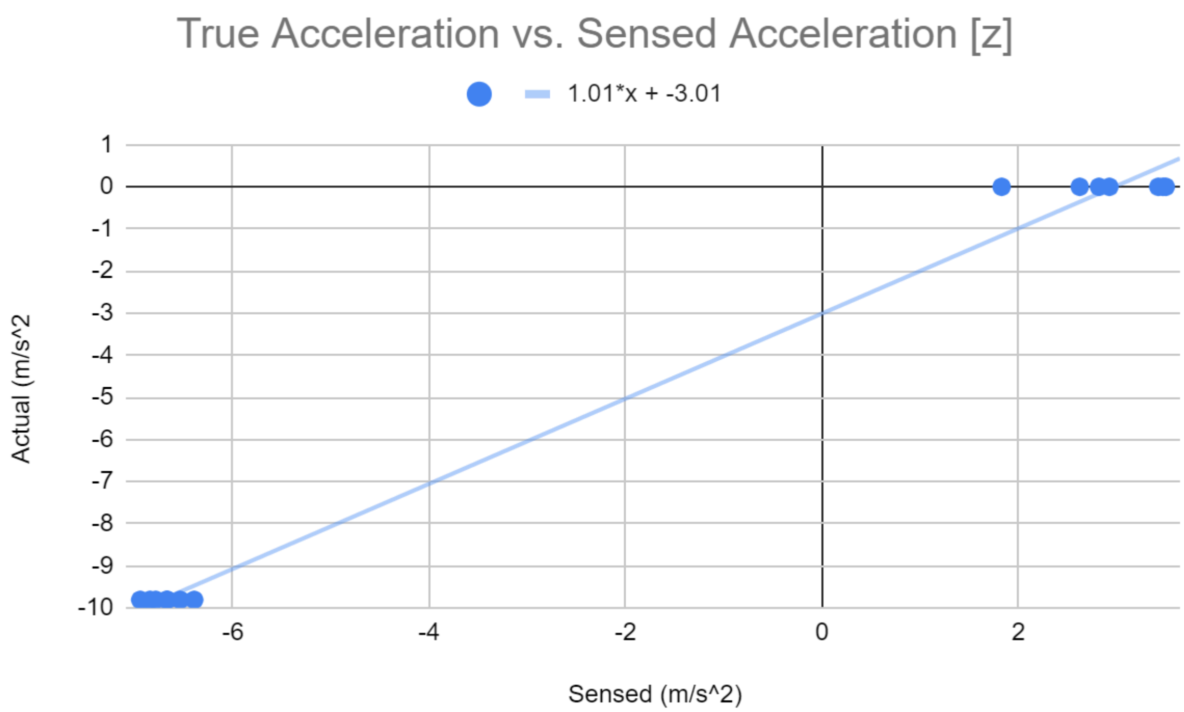
Method: For all acceleration measurements, we obtained two data points to create a line and solve for gain and offset. One data point was found by keeping the device still on a flat surface (aligning the desired axis vertically), and the other was found dropping the device (along the desired axis). The acceleration read from the first data point should have been equal to the acceleration of gravity (9.81 m/s^2). The true acceleration for the second point should be zero.

2b. Calibrating Y-Acceleration



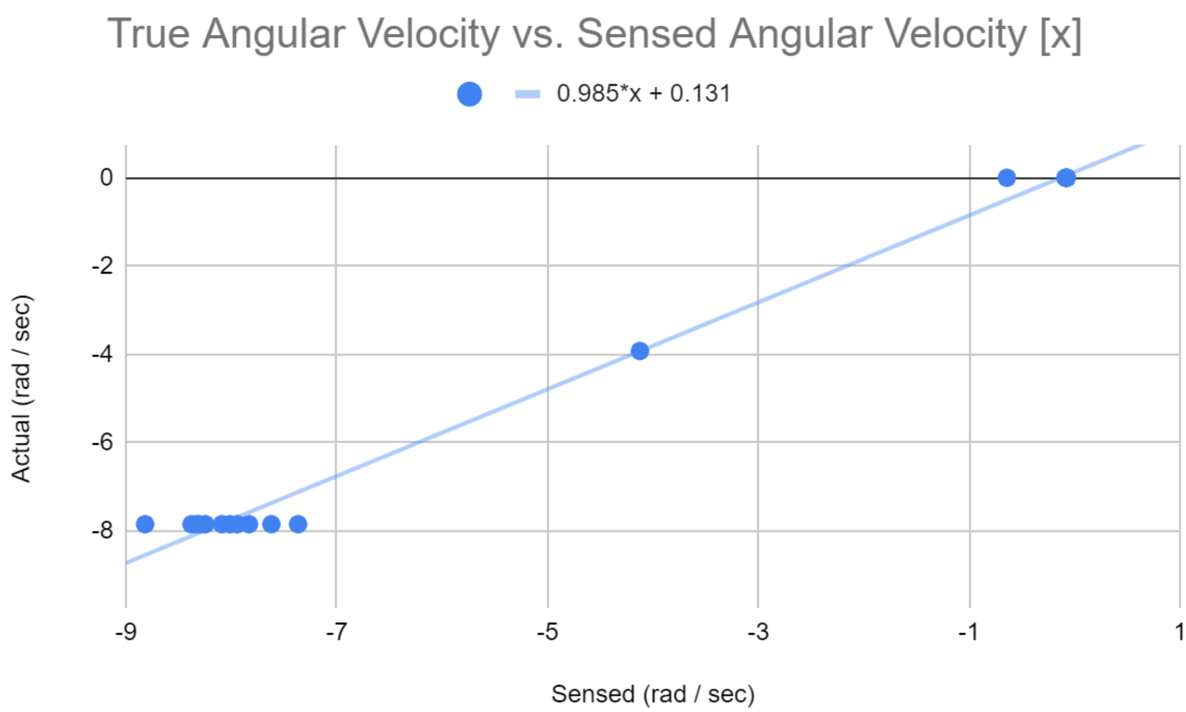
Equation: $Actual = 1.01(Sensed) - 0.285$

2c. Calibrating Z-Acceleration



Equation: $Actual = 1.01(Sensed) - 3.01$

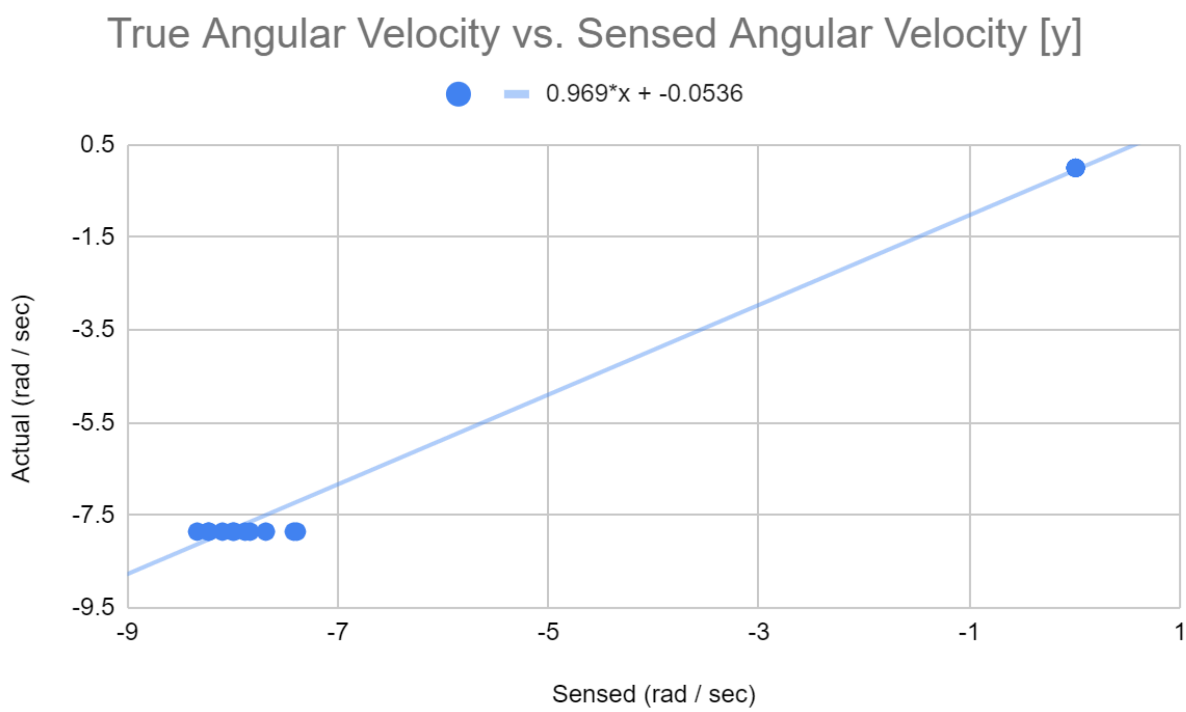
2d. Calibrating Angular Velocity Around X-axis



Equation: $Actual\ =\ 1.01(Sensed)\ -\ 0.171$

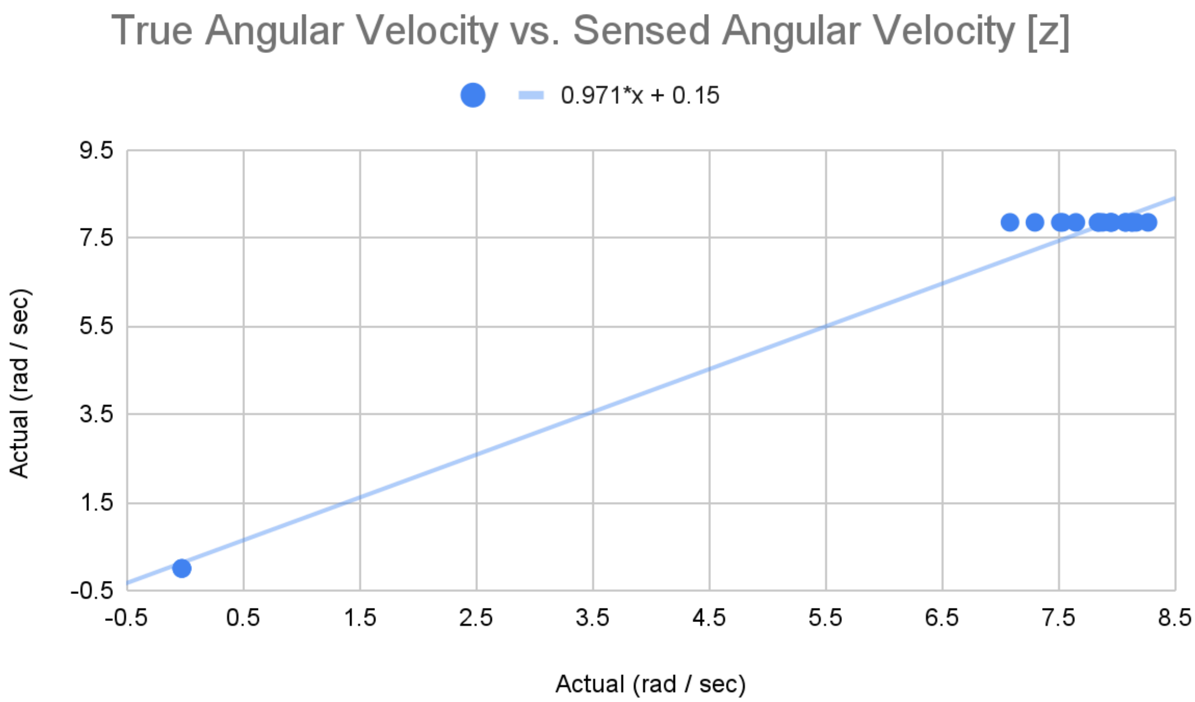
Method: We calculated the angular rate across 3-axes by taping the Telemetry device to a lathe in the Precision Machining Lab (aligning the desired axis parallel to the axis of rotation). The first set of data points should measure the angular rate at a standstill. Then, the device measures rate as the lathe begins rotating to the set value of 75 RPM (7.854 RAD / sec).

2e. Calibrating Angular Velocity around Y-axis



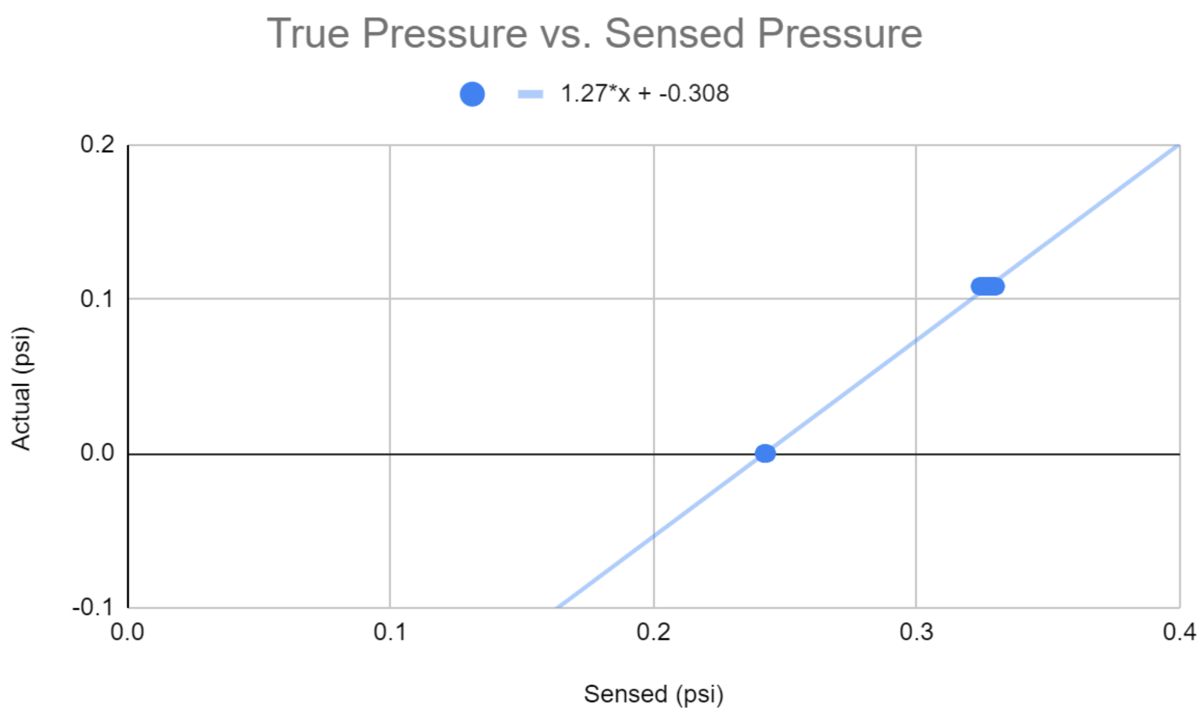
Equation: $Actual\ =\ 1.02(Sensed)\ +\ 0.00914$

2f. Calibrating Angular Velocity around Z-axis



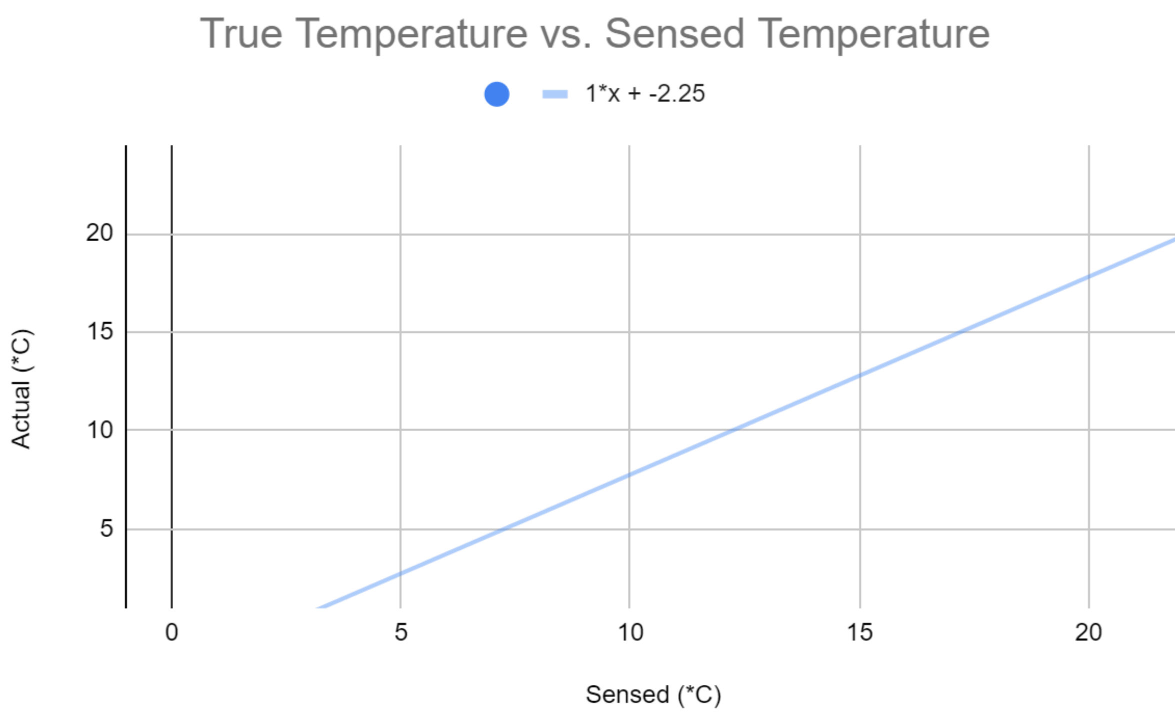
Equation: $Actual = 1.01(Sensed) - 0.023$

2g. Calibrating Pressure



Equation: $Actual\ =\ 0.785(Sensed)\ +\ 0.242$
Method: We put the end of the pressure tube under 3 inches of water, knowing that the hydrostatic pressure should be around 0.1 psig. The other datapoint we used was simply atmospheric pressure, which should be around 0 psig.

2h. Calibrating Temperature



Equation: $Actual = 0.997(Sensed) + 2.24$
Method: We placed the end of the thermistor into a cup of ice, knowing it should measure around 0ºC. The other datapoint was the ambient room temperature, which was nearly 71ºF

3. Appendix (Calibration Validation)

The google sheet we used to compute all values can be found here:
https://docs.google.com/spreadsheets/d/1F5wCa8M3J2NTEYr7rv57GLLvzyjeX8EDRBO2N87gIHA/edit?usp=sharing

3a. Validating accelerometer calibration

The most challenging aspect of calibrating the accelerometer was holding it in a way such that the axis were aligned vertically, such that we were actually measuring the acceleration of gravity. Here, we will compare the gain and offset in the equations that we reported to the gain and offset as determined by examining all three measurements of the accelerometer at once. We know that:

$$\sqrt{a_x^{\;2} + a_y^{\;2} + a_z^{\;2}} = 9.81\, m/s^2$$

Another way of calculating gain is by adding factors to this expression and calculating for them using recorded values of acceleration (from three different trials in three different directions):

$$\sqrt{ka_x^{\;2} + la_y^{\;2} + ma_z^{\;2}} = 9.81\, m/s^2$$

Averaging the data from trials in three different orientations, we can set up the following system of equations where x1, x2, and x3 represent k, l, and m respectively.

$$\begin{aligned}
10.008\text{^}2\; x_1 &+ -0.862\text{^}2\; x_2 + 3.987\text{^}2\; x_3 + \;\; x_4 = 9.81\text{^}2 \\
1.032\text{^}2\; x_1 &+ 9.598\text{^}2\; x_2 + 2.569\text{^}2\; x_3 + \;\; x_4 = 9.81\text{^}2 \\
-0.181\text{^}2\; x_1 &+ -0.4959\text{^}2\; x_2 + -6.697\text{^}2\; x_3 + \;\; x_4 = 9.81\text{^}2
\end{aligned}$$

This online calculator returns the following values for gain for acceleration in each direction.

$$x_1 = 0.6146$$
$$x_2 = 0.8842$$
$$x_3 = 2.1404$$

These values are much farther from "1" than the values that we found in our calibrating, suggesting that the accelerometer values are farther off than we would expect. However, this initial calculation does not account for any offset, and from our original calibration we expect the acceleration in the z-axis to have a significant offset of -3.01 m/s^2 (nearly thirty percent of the "true value). Accounting for this in the calculation:

$$10.008^2 x_1 + (-0.862)^2 x_2 + (3.987-3.01)^2 x_3 + x_4 = 9.81^2$$
$$1.032^2 x_1 + 9.598^2 x_2 + (2.569-3.01)^2 x_3 + x_4 = 9.81^2$$
$$(-0.181)^2 x_1 + (-.4959)^2 x_2 + (-6.697-3.01)^2 x_3 + x_4 = 9.81^2$$

$$x_1 = 0.9435$$
$$x_2 = 1.0316$$
$$x_3 = 1.0183$$

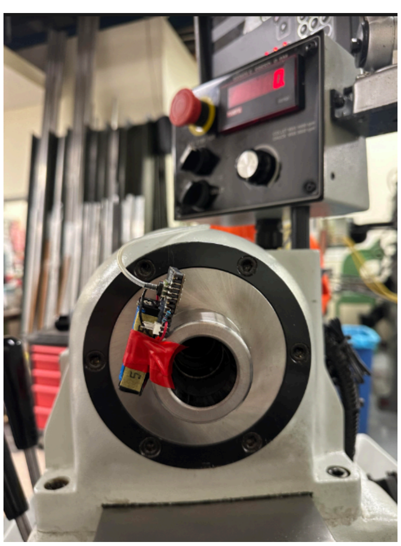
The values are much closer to what was achieved in the original calibrations. We can further refine this by including the offsets we calculated for x and y:

$$(10.008-.451)^2 x_1 + (-0.862+.332)^2 x_2 + (3.987-3.01)^2 x_3 + x_4 = 9.81^2$$
$$(1.032-.451)^2 x_1 + (9.598+.332)^2 x_2 + (2.569-3.01)^2 x_3 + x_4 = 9.81^2$$
$$(-0.181-.451)^2 x_1 + (-.4959+.332)^2 x_2 + (-6.697-3.01)^2 x_3 + x_4 = 9.81^2$$

$$x_1 = 1.0400$$
$$x_2 = 0.9704$$
$$x_3 = 1.0166$$

Now, calculating percent deviation from the gain values here to the values from the original calibration we find a difference of:

X-Acceleration: 1.96%
Y-Acceleration: 1.18%
Z-Acceleration: 0.594%



3b. Validating gyroscope calibration:

In order to achieve an accurate calibration for the gyroscope, we attached the accelerometer rigidly to the lathe in order to spin it at a very regular speed and took care when aligning the axis with the axis of the lathe.

3c. Validating pressure sensor calibration
We were able to determine what the true value of the (hydrostatic) pressure would be if we put the sensor tube 3 inches under water using the formula:

$P = \rho g h;\ \rho = 1000\ kg/m^3;\ g = 9.81\ m/s^2;\ h = 3\ in = 7.62\ cm = 0.0762\ m$

$P = 747\ Pa = 0.108\ psig$

(Pa to psig unit conversion from Google)

Since our other datapoint was just the atmosphere, we knew by definition that this would simply be 0 psig

3d. Validating thermistor calibration
One datapoint was from a cup of ice. Based on the fact that it was gradually melting, we knew it would be at its standard saturation temperature of 0ºC. We verified this with a temperature gun, which showed it was around the same number.
Our second datapoint was room temperature, which we reasonably assumed to be around 71ºF = 22.67ºC.
We found these numbers to be acceptable calibration points because they were well within the range of temperatures that this sensor could handle. We also ensured to leave the thermistor in each substance for around 1 minute to ensure the sensor was at thermal equilibrium with the surrounding substance. We observed this happening by seeing the live readings settle around a single value.

Accreditation:
Lauren: gathering data, accelerometer and gyro validation, method writing, sensor data versus time graphs, calibration graphs, extra credit calculations.
Ashna: gathering and cleaning experimental data, calibration graphs, some extra credit calculations.
Jake: gathering data, calibration graphs, method writing.

4. **Extra Credit**

We used the built in functions in google sheets to calculate the statistical variance under conditions where the sensor was meant to read a value of 0. The average values (calibrated and uncalibrated) under these conditions are provided for comparison.

Measurement	**Average (uncalibrated) at truth = 0**	**Average (calibrated using equations from section 2)**	**Variance at Truth = 0**
X-Acceleration	**0.447**	**0.00450**	**0.0293**
Y-Acceleration	**0.632**	**0.0521**	**-0.285**
Z-Acceleration	**2.94**	**-0.0384**	**0.0349**
X-Gyro	**-0.1718**	**-0.0383**	**0.0531**
Y-Gyro	**0.00914**	**-0.0447**	**0.000000476**
Z-Gyro	**0.0675**	**0.216**	**0.0328**
Pressure	**0.297**	**0.0697**	**0.00720**
Temperature	**2.313**	**0.0628**	**0.0933**