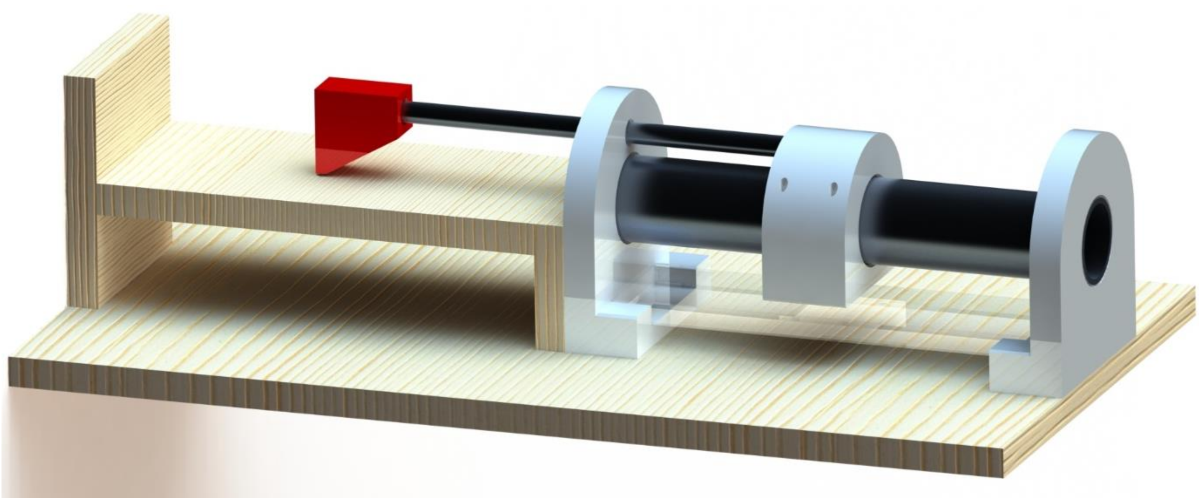
University of Waterloo

Department of Mechanical and Mechatronics Engineering

Measuring Length Using a Potentiometer



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March 22nd, 2023

Summary of the Design and Construction

Components of the Potentiometer

Figure 1 illustrates the first potentiometer design.

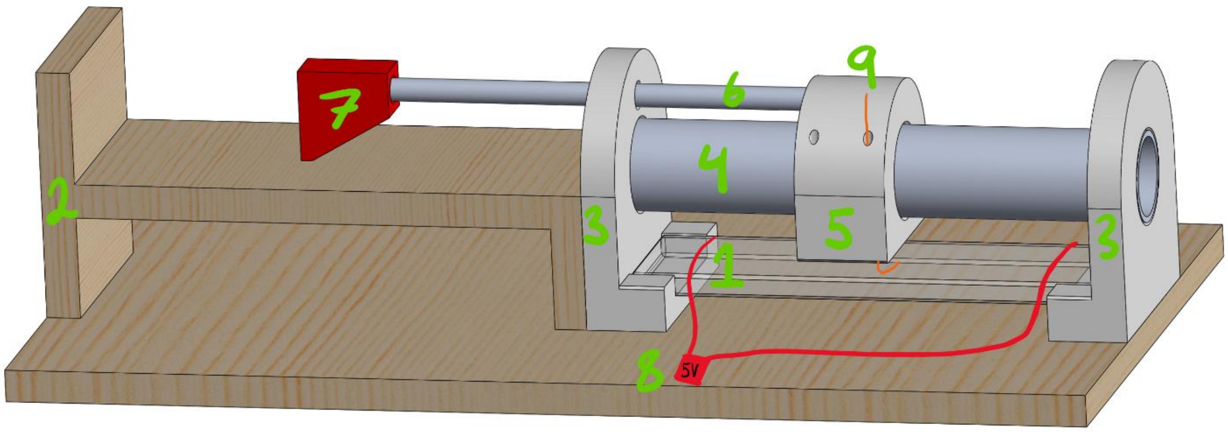

Figure 1: Potentiometer design

The main components of the potentiometer are:

1. Resistive track
2. Measurement stand
3. End blocks
4. Collar pipe
5. Collar
6. Plunger rod
7. Plunger tip
8. Power supply wire
9. Wiper wire

Using the Potentiometer

The function of the design is as follows:

1. The object to be measured is placed on the measurement stand.
2. The slider is then adjusted so the object is pressed against the end of the measurement stand.
3. A voltage is recorded, and displacement is calculated.

Construction of the Potentiometer

Figure 2 illustrates the final constructed potentiometer. Construction of the system began with fabrication. First, the end blocks, collar, and plunger tip were 3D printed. Then, the acrylic core for the wire was cut using a laser cutter. Next, the wooden components were cut, and glued together. Then, the metal rods were lathed to the correct size and tolerance. Finally, the copper wiper was bent to the correct shape. After the fabrication process was complete, assembly began. The resistive track was constructed by coiling 36-gauge Nichrome wire around the acrylic core. Then, all the components were glued together. Finally, the resistive track was connected to the power source using copper hookup wire.

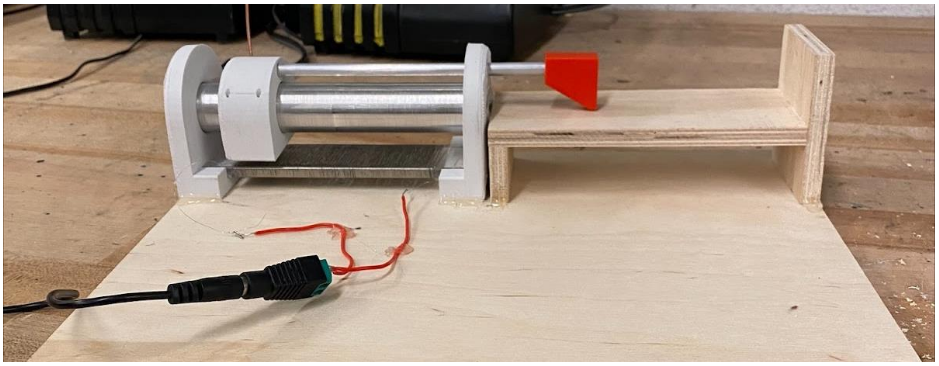

Figure 2: Final Construction of Potentiometer

Working Theory of the Potentiometer

A linear potentiometer uses the theory of voltage divider to produce a displacement value from a voltage. Figure 3 shows a basic voltage divider circuit, with two resistors and a voltage measurement over the second resistor. The potentiometer uses one resistor with a movable wiper making R1 and R2 dependent on the location of the wiper along the resistive track. Since the resistance of R1 and R2 are now dependent on position, the voltage is also dependent on the wiper position allowing us to create a plot of displacements to their corresponding voltage values.

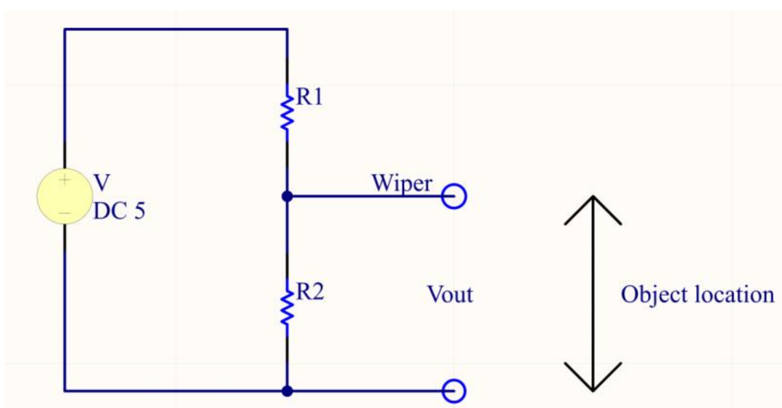

Figure 3: Electrical Schematic of Potentiometer Function

Assumptions for Design

The estimated uncertainty and accuracy of the potentiometer was based on the following assumptions. First, it was assumed there would be an insignificant or no variation in output from the voltage source. The accuracy of the potentiometer relied on the calibration where voltage was recorded for various known measurements. A fault in the power source during the measurement of an object causing a difference from the voltage during calibration would result in the potentiometer being inaccurate.

Another assumption was an even coiling of nichrome wire along the acrylic piece. If at one point the nichrome wire was wound unevenly leaving some sections with extra nichrome wire or no nichrome wire the voltage measurements would be thrown off and result in an inaccurate reading. The final assumption was the accuracy of the multimeter used to take measurements of the voltage. The accuracy of the multimeter would result directly in the accuracy of the potentiometer.

Calibration Procedure and Results

Apparatus and Procedure

Figure 4 illustrates how parallels and gauge blocks were used to perform calibration.

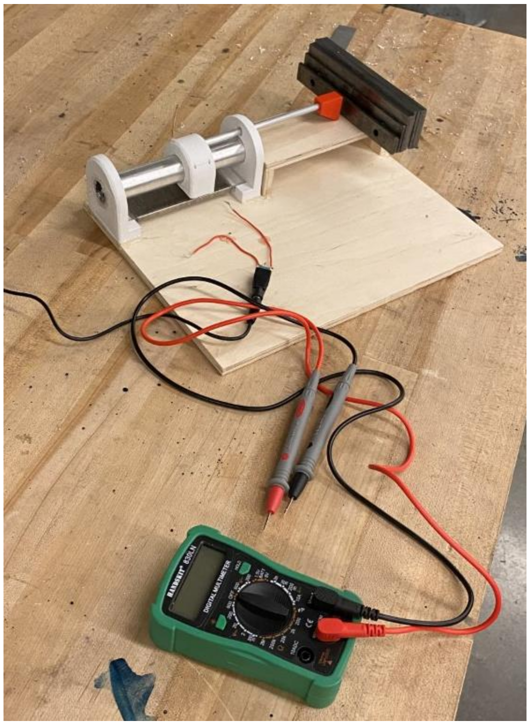

Figure 4: Calibration with parallels

The following procedure was used to collect calibration data:

1. Measure and record the thickness of a parallel using a digital height gauge.
2. Place it on the measurement platform against the backing plate.
3. Slide the plunger against the parallel.
4. Using a multimeter, place the positive probe on the positive side of the voltage source and the negative probe on the wiper and record the voltage.
5. Repeat steps 1-4 keeping the previously placed parallels on the measurement platform and continue until all parallels in the set are used.
6. Repeat steps 1-4 using a gauge block instead of a parallel and continue until the approximate maximum length that the unit can measure it recorded.
7. Repeat steps 1-4 using parallels and gauge blocks to get similar values that were previously recorded to check for random error.

Calibration Data and Calibration Curve

Table 1 presents the calibration data.

Table 1: Calibration Data

True Length (mm)	Recorded Voltage (V)
0	5.24
3.29	5
6.68	4.92
10.13	4.77
13.35	4.55
16.79	4.3
20.29	4.13
23.61	4
27.09	3.92
30.33	3.6
33.79	3.36
37.03	3.1
40.27	2.99
43.48	2.93
46.72	2.64
49.95	2.57
52.94	2.28
56	2.16
59.21	2
84.58	0.47
91.19	0.37
3.36	5.05
6.78	4.97
8.31	4.86
25.37	3.82
80.27	0.76

Figure 5 illustrates the calibration curve plot. From the plot, the calibration equation/equation of the line of best fit was:

$$l = -17.976V + 94.86$$
$$with$$
$$l = length\ [mm]$$
$$V = voltage\ [V]$$

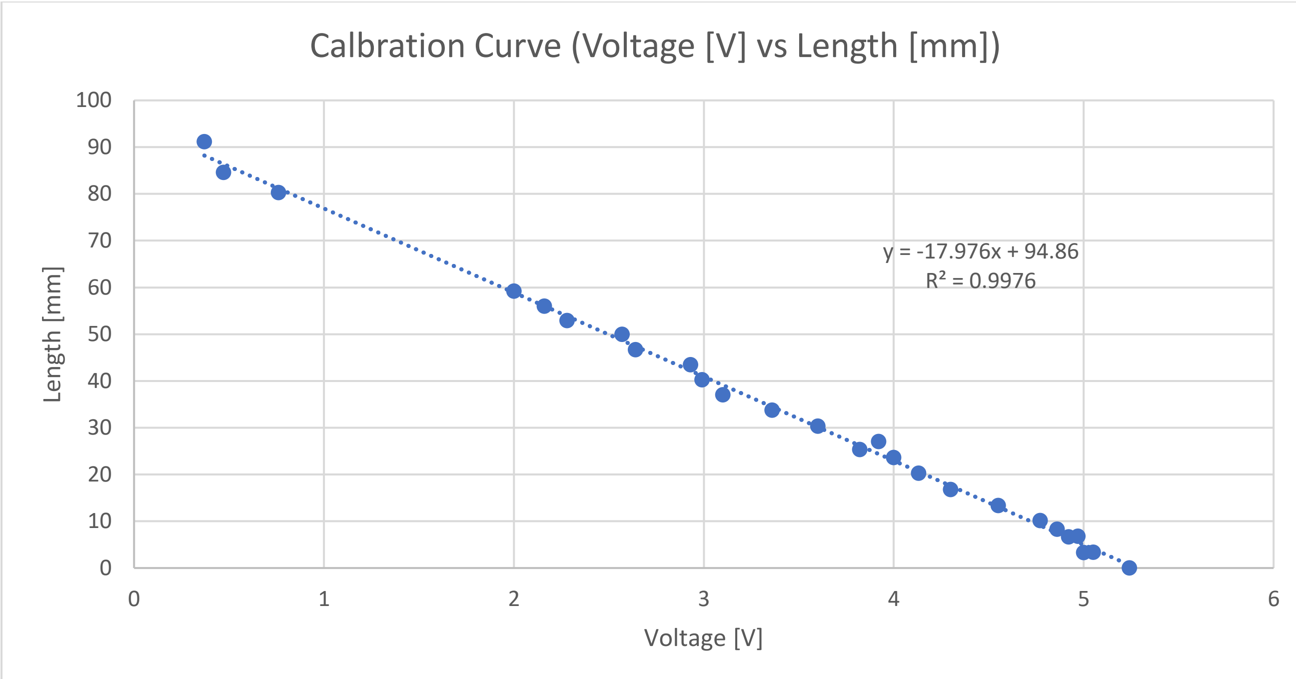

Figure 5: Calibration Curve

Uncertainty Analysis Results

Deviation Plot

Table 2 presents the calculated length and deviation of the true length to the calculated length. The calculated length values were calculated using the calibration equation and the deviation was calculated by subtracting the true length from the calculated length.

Table 2: Calculated Length and Deviation Data

True Length (mm)	Recorded Voltage (V)	Calculated Length (mm)	Deviation of True Length to Calculated Length (mm)
0	5.24	0.66576	-0.66576
3.29	5	4.98	-1.69
6.68	4.92	6.41808	0.26192
10.13	4.77	9.11448	1.01552
13.35	4.55	13.0692	0.2808
16.79	4.3	17.5632	-0.7732
20.29	4.13	20.61912	-0.32912
23.61	4	22.956	0.654
27.09	3.92	24.39408	2.69592
30.33	3.6	30.1464	0.1836
33.79	3.36	34.46064	-0.67064
37.03	3.1	39.1344	-2.1044

40.27	2.99	41.11176	-0.84176
43.48	2.93	42.19032	1.28968
46.72	2.64	47.40336	-0.68336
49.95	2.57	48.66168	1.28832
52.94	2.28	53.87472	-0.93472
56	2.16	56.03184	-0.03184
59.21	2	58.908	0.302
84.58	0.47	86.41128	-1.83128
91.19	0.37	88.20888	2.98112
3.36	5.05	4.0812	-0.7212
6.78	4.97	5.51928	1.26072
8.31	4.86	7.49664	0.81336
25.37	3.82	26.19168	-0.82168
80.27	0.76	81.19824	-0.92824

Figure 6 illustrates the deviation plot.

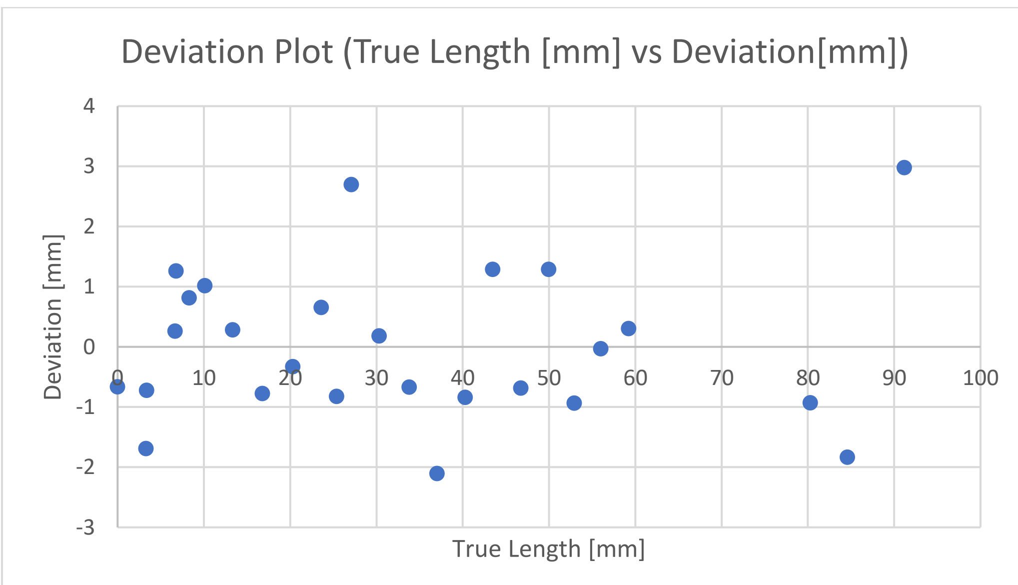

Figure 6: Deviation Plot

Estimate of Maximum Uncertainty

The maximum and minimum deviation values were selected from Table 2. The maximum uncertainty of the sensor was approximately +2.98/-2.10 mm.

Proof of Systematic and Random Error

The line of best fit was determined to have an R^2 value of 0.9976 meaning there is low systematic error since there is minimal deviation from linear behaviour.

Since there is no relationship with the data in Figure 6, there is random error within the system. Specifically, true values such as 3.29mm and 3.36mm have deviations of -1.69 and -0.72 respectively.

Since the deviation is not repeatable for similar values, there are outside factors that are resulting in random error.

Conclusions and Recommendations for Future Work

Recommendations for future work for accuracy:

1. Winding the nichrome wire around the acrylic plate meticulously with more equality will enable to increase the accuracy of the measurement.
2. Wiring the acrylic plate without leaving any space at the end that is close to the end of the wooden floorboard (further from the wooden stand where an object is put) will enable us to measure larger items than what can be measured currently.
3. Using a wiper (coil moving along the steel pipe) with smaller diameter will allow to reduce the thickness of it, which will also enhance the accuracy.
4. The surface of the wiper touching the wire on the acrylic plate is not completely parallel, which impacts the data collected. Bending the wiper to a perfect right angle can be one of the solutions to fix this error.
5. Fit on the end block is not tight enough to the plunger rod, allowing rotation of the collar, which affects the voltage measurement during calibration. Solutions to this problem include:
    a. Adjusting the thickness of the end block to reduce lateral plunger movement.
    b. Create a tighter fit through better manufacturing processes.
    c. Using a square collar pipe or plunger rod.
6. Use bearings instead of 3D printed holes only. This would increase rigidity in the system which would reduce the error.
7. Use 80-20 aluminum extrusion to construct the entire assembly. This would reduce errors since the inaccuracies of the 3D prints cause unwanted movement within the system.
8. Marking a fixed space on where to put each probe for voltage measurement at the part where the nichrome wire and hookup wire are connected will help prevent any unwanted error that may be created.