Design & Calibration of a Measurement System

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1 Design

The objective of the project was to design, build and calibrate a system to measure length. The instrument was designed around a circuit which produces a variable resistance based on the position of a sliding block. An Arduino supplies 3.3V to a series of resistors that carry constant current, one of which is a 120 mm long cylinder of graphite. The sliding block moves a wiper along the graphite, resulting in a variable voltage in that wire. The voltage is translated into a length measurement by the signal modification system as governed by Ohm's Law (1).

$$V = IR \tag{1}$$

The contact point between the graphite and the rest of the circuit is a small threaded rod, which is maintained under tension by two springs to ensure constant contact between the wire and the graphite. Figure 1 on page 1 shows a close up of the mechanical design of the instrument.

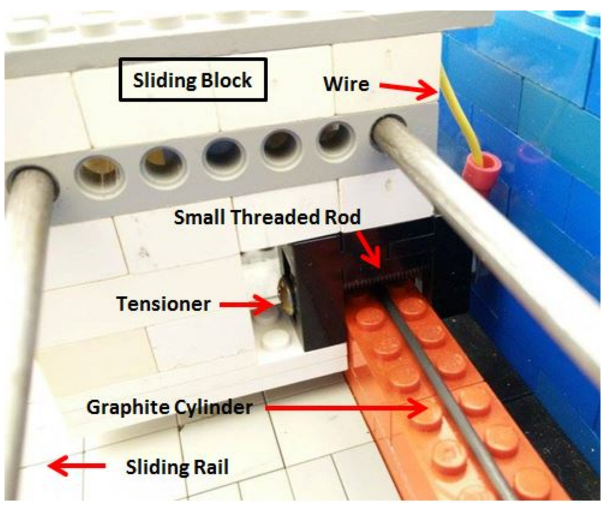

Figure 1: Close up of mechanical design of instrument.

The voltage in the wiper of the variable resistor is input to the analog-to-digital converter on the Arduino. Since the analog-to-digital converter expects a range of voltages from 0 − 3.3V, it was important the output voltage from the system cover that whole range. By using an operational amplifier it was possible to scale the relatively small voltage range across the graphite to cover a range of approximately 0 − 3V. Figure 2 on page 2 shows the circuit used. R4 is the graphite variable resistor, whereas R5 controls the amplification of the signal. The line from pin 7 of amplifier is connected to the analog-to-digital converter on the Arduino. The result of the analog-to-digital conversion is translated to a length measurement using the linear relationship found during calibration. The result is indicated on the LCD display on the printed circuit board connected to the Arduino.

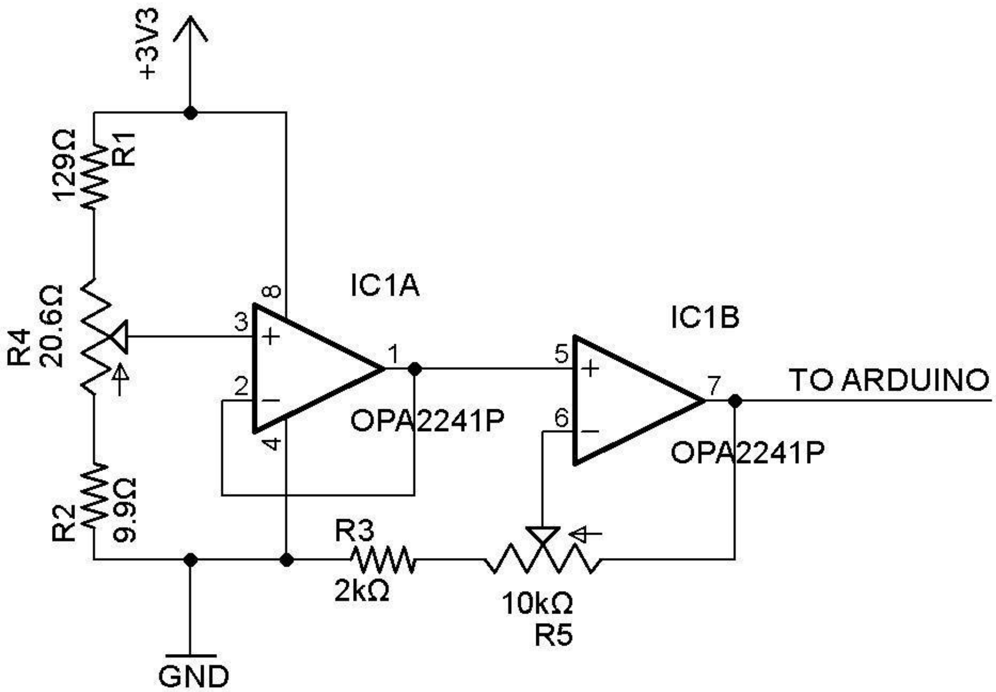

Figure 2: Circuit diagram.

The design of the instrument relies on several assumptions. Firstly, the cross-sectional area of the graphite must be constant along its length. Also, that the construction of the instrument is perfect (i.e. the contact surfaces are smooth, the slider holds its position perfectly, the graphite is fixed in placed and the slider does not twist). Lastly, it is assumed that the Arduino supplies a constant 3.3V.

2 Calibration

The instrument was calibrated using LEGO® blocks as a secondary standard because of the tight tolerances to which they are manufactured. The lengths of the blocks were measured using a calliper before they were used to calibrate the instrument.

The following procedure was used to obtain calibration data:

1. A construction of LEGO® blocks 0 – 12 dots in length is measured using a calliper.
2. The construction is placed in the instrument.
3. The slider is adjusted to that it lightly contacts the construction.
4. The scaled voltage reading is read from the LCD screen.
5. Steps 1 – 4 are repeated 26 times for increasing lengths of LEGO® blocks. Table 1 on page 3 shows two samples for each length of dots from 0 – 12.

Figure 3 on page 4 shows the calibration curve obtained by plotting the known distances against the measured scaled voltages. A relationship between the scaled voltage and the corresponding length was obtained (2).

$$V(x) = 30.355x + 365.16 \tag{2}$$

Table 1: Deviation data.

# Dots	Actual Length (mm)	Scaled Voltage (V)	Measured Length (mm)	Deviation (mm)
0	0	368	0.093	-0.093
0	0	366	0.028	-0.028
1	7.88	602	7.802	0.078
1	7.88	601	7.769	0.111
2	15.83	843	15.742	0.088
2	15.83	846	15.841	-0.011
3	23.78	1091	23.912	-0.132
3	23.78	1090	23.879	-0.099
4	31.8	1330	31.786	0.014
4	31.8	1328	31.720	0.080
5	39.8	1579	39.989	-0.189
5	39.8	1576	39.890	-0.090
6	47.87	1818	47.862	0.008
6	47.87	1819	47.895	-0.025
7	55.93	2063	55.933	-0.003
7	55.93	2062	55.901	0.029
8	64	2302	63.807	0.193
8	64	2305	63.906	0.094
9	71.86	2543	71.747	0.113
9	71.86	2545	71.813	0.047
10	79.86	2787	79.785	0.075
10	79.86	2789	79.851	0.009
11	87.9	3033	87.889	0.011
11	87.9	3032	87.856	0.044
12	95.88	3280	96.026	-0.146
12	95.88	3281	96.059	-0.179
			1 σ	0.097
			3 σ	0.292

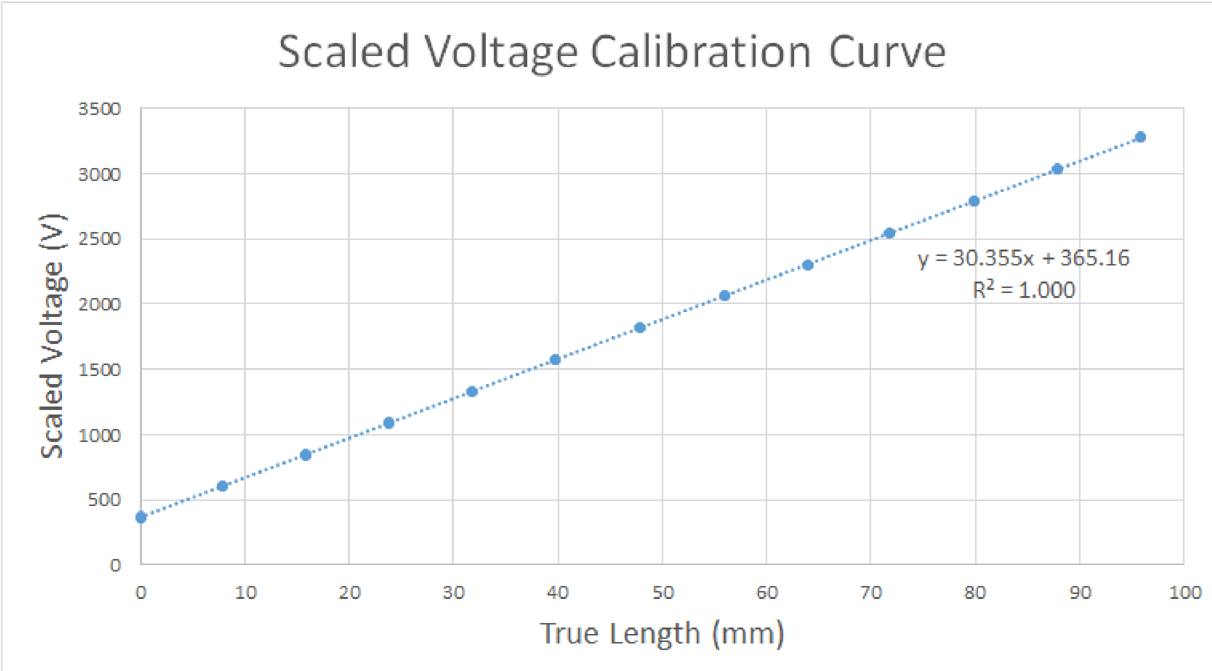

Figure 3: Calibration curve.

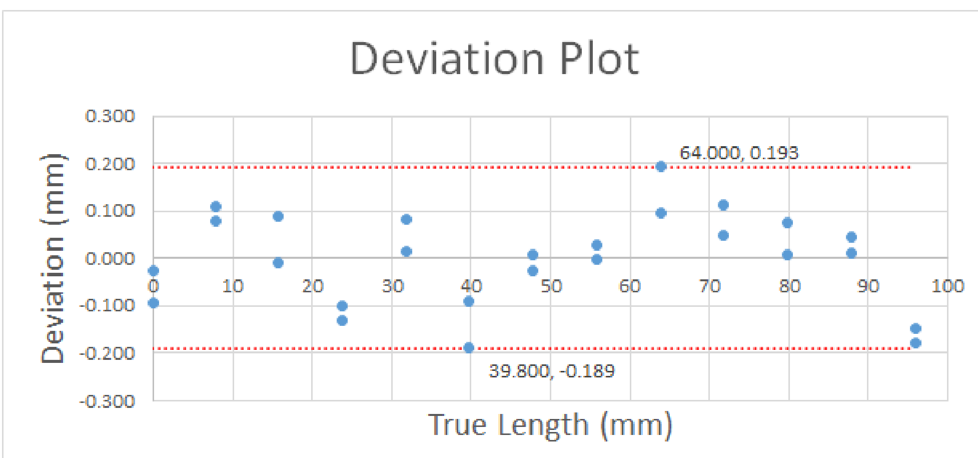

Figure 4: Deviation of measured lengths from true lengths.

3 Analysis

By manipulating the equation derived from the calibration curve, it was possible to approximate length as a function of scaled voltage (3).

$$x(V) = \frac{V - 365.16}{30.355} \tag{3}$$

Plotting the difference between the calculated distance and the actual distance, a deviation plot for the calibration data was obtained. Figure 4 on page 4 shows the deviation plot of the data. Table 1 on page 3 shows the deviation data.

The maximum deviation of the 26 samples was 0.193 mm and the standard deviation was 0.097 mm. The distribution of the deviations was plotted and a Shapiro-Wilks test was applied to test for normality. The results found a p-value of 0.05 and a threshold of 0.92. Since the threshold was greater than the p-value, the distribution of the deviations was normal. It was then permissible to set the maximum uncertainty of the instrument to 0.292 mm (3 standard deviations).

4 Conclusion

A linear potentiometer was constructed using a graphite cylinder as a variable resistor. The Arduino converted the analog voltage signal to a length measurement displayed on the integrated LCD screen. The instrument has measurement range of approximately $0 - 120$ mm and was calibrated using LEGO® blocks. The uncertainty of the instrument was found to 0.292 mm with a confidence of 99.7%.

Some changes could be applied to the instrument to improve its versatility and accuracy. Resistive wire could replace the graphite, increasing the uniformity of the cross-sectional area, and hence resistance, along the wire. Resistive wire is stronger than graphite therefore would not deform due to contact with the slider; this would prevent changes in the resistance of the wire. To account for the lower resistivity of resistive wire the gain of the operational amplifier could be adjusted. Secondly, a constant force could be applied to the sliding block to hold its position. A pulley system or an elastic force attached to the end wall of the instrument could provide this force. Finally, an algorithm could be applied to remove the noise in the output of the analog-to-digital conversion and thereby smooth the reading.