MTE 201 Lab #1

Data Collection and Analysis

Department of Mechanical and Mechatronics Engineering

A Report Prepared For:

MTE 201

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Introduction

Through the use of first principles, a distance measurement device can be assembled without the use of a prefabricated system for the same purpose. Using existing standards set by gauge blocks for calibration, and inches as the fundamental unit, a new system was designed and built to serve the purpose of displacement measurement. The design/construction, calibration, uncertainty analysis, and future recommendations are provided in this report.

Design and Construction

To execute the goal of building a distance measurement device, it was decided to assemble a system resembling that of a digital caliper. This was achieved with the use of a potentiometer and rack and pinion system, as seen in Figure 1. The object to be measured is fit between the jaws of the caliper, and the distance the pinion travels across the rack from the datum is recorded. To convert this analogue measurement to a digital display, a voltage potentiometer is connected to the circular gear. As the pinion rotates along the rack, so too will the potentiometer, which will output a voltage reading. To process this signal, the potentiometer is wired to an Arduino Uno (Figure 2).

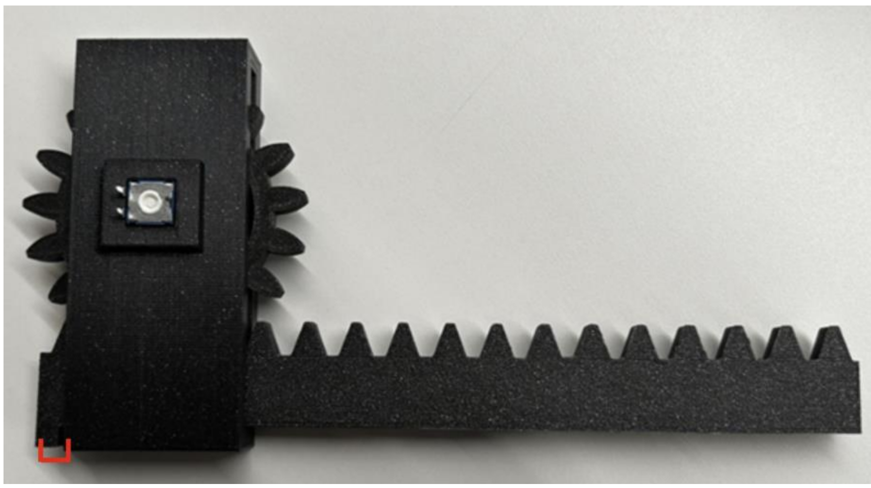

Figure 1 - Final Design, Caliper Jaws Indicated in Red

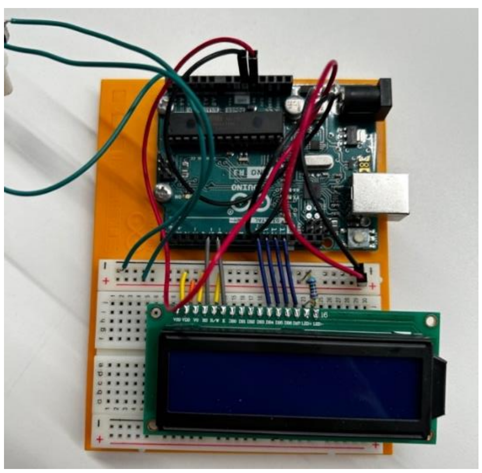

Figure 2 - Arduino Uno

The major design constraint with this set-up is attributed to the range of rotation for the potentiometer. After testing, it was determined that measurements would be limited to 200 degrees of rotation. Taking the project requirement of measuring up to a length three 2x4 LEGO bricks into account, the caliper would need to measure a linear distance of approximately 10cm. With the parameters of 10cm of pinion circumference over 200 degrees, a 6 cm pitch diameter gear was used.

Every element of the system, other than the electrical components (potentiometer and Arduino Uno) was designed in SolidWorks and 3D printed. To hold the assembly together, a sleeve was printed that allows for the rack to slide through and rotate the pinion which is held in the housing with the potentiometer pin. The potentiometer itself simply sits in a slot that was printed to its dimensions. The use of 3D printing led to design restrictions in wall and gear thickness, and consideration of printing tolerances compared to the model. There were a series of prints that failed or printed with a warped structure. However, the final product has accurate and consistent fits and tolerances.

A single flaw in the design was encoutered during the assembly of the device. Due to limited time and resources the potentiometer that was used was not intended to be connected to a pinion to drive rotation. Fixing the gear to the rotating dial on the potentiomer inside the measuring device proved difficult and lowered the confidence of the system operating to the greatest accuracy. The solution involves using a thin sheet of paper around the rotating dial so it properly fits into the gear. There is a possibility that this connection point became a source of systematic error, as rotation of the device may not have been true to that of the gear due to slipping.

Calibration

To calibrate the digital caliper, the group used 8 samples from a gauge block set, similar to that seen in Figure 3 below. These machined blocks are highly accurate, with tolerances less than ±. 000025µin.

Figure 3: Gauge Block Set

The calibration process followed a set procedure. After selecting the desired test distances from the gauge block set, each sample was measured 3 times using the measurement tool, which was set to output the analog output (10-bit numerical value from 0 to 1023) representing the voltage across the potentiometer. The true distance and analog outputs over the trials were tabulated across the samples (Table 1) and inputted into a calibration curve using Excel. The completed calibration curve is shown below in Figure 4.

Table 1: Analog Output and True Distances Across Trials

True Distance (in)	**Analog Output**		
Trial Number	**1**	**2**	**3**
0	951	944	946
0.50	809	841	807
1.00	705	707	699
1.50	590	594	591
2.00	484	487	484
2.50	397	403	387
3.00	276	291	279
3.50	151	162	161
4.00	19	37	22

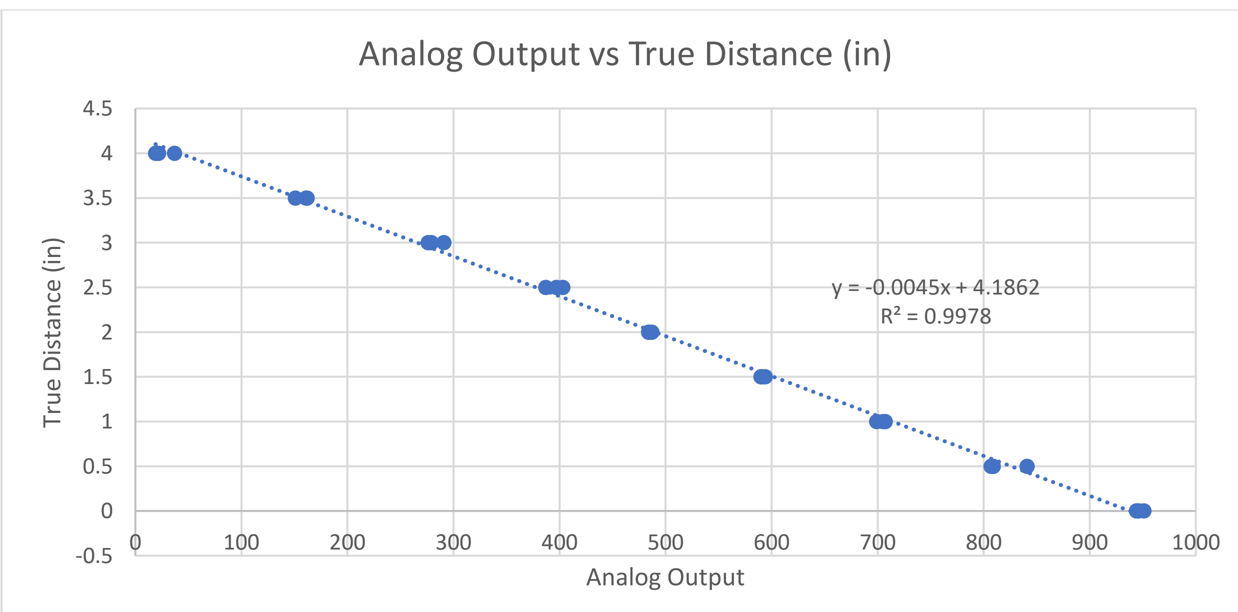

Figure 4: Analog Output vs True Distance (in)

From the calibration curve, a calibration equation was derived, where y represents the true distance in inches, and x represents the analog output of voltage across the potentiometer.

$$y(x) = -0.0045x + 4.1862$$

This equation was implemented within the Arduino output code, so the calipers displayed a distance in inches, as a function of the analog voltage across the potentiometer.

Uncertainty Analysis

To calculate the maximum uncertainty for the measurement system, the group used the calibration equation to calculate measured values compared to standard ones. Table 2 below displays the calculated distance compared to true distance for each trial, and the deviation between the two.

Table 2: Deviation Table

True Distance (in)	Analog Output	Calculated Distance (in)	Deviation
0	951	-0.0933	-0.0933
0.50	809	0.5457	0.0457
1.00	705	1.0137	0.0137
1.50	590	1.5312	0.0312
2.00	484	2.0082	0.0082
2.50	397	2.3997	-0.1003
3.00	276	2.9442	-0.0558
3.50	151	3.5067	0.0067
4.00	19	4.1007	0.1007
0	944	-0.0618	-0.0618
0.50	841	0.4017	-0.0983
1.00	707	1.0047	0.0047
1.50	594	1.5132	0.0132
2.00	487	1.9947	-0.0053
2.50	403	2.3727	-0.1273
3.00	291	2.8767	-0.1233
3.50	162	3.4572	-0.0428
4.00	37	4.0197	0.0197
0	946	-0.0708	-0.0708
0.50	807	0.5547	0.0547
1.00	699	1.0407	0.0407
1.50	591	1.5267	0.0267
2.00	484	2.0082	0.0082
2.50	387	2.4447	-0.0553
3.00	279	2.9307	-0.0693
3.50	161	3.4617	-0.0383
4.00	22	4.0872	0.0872

The deviation and true distance are plotted in a deviation plot below to determine the maximum uncertainty. Figure 5 displays the deviation plot.

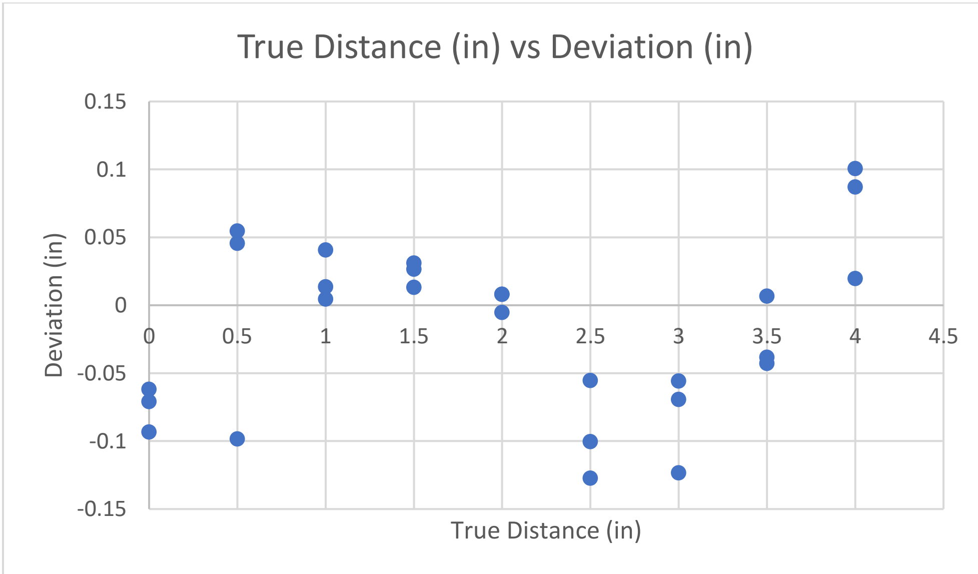

Figure 5: Deviation Plot

Using Table 2 and the deviation plot above, the highest positive deviation is 0.1007 inches, and largest negative deformation is -0.1273 inches. Therefore, the maximum uncertainty is estimated to be around ±0.13 inches (rounding up to provide adequate room for random error).

Based on the deviation plot, there is evidence of systematic error. Systematic error is fixed, biased error, and the deviation plot shows the majority of measured distances have definite variance compared to true distances. This can be because of calibration error, where the calibration equation was fit with a linear relationship when perhaps higher order equations would fit better. Any R^2 value that differs from 1 means there is slight deviation.

There is also random error. As shown in Table 1, the same standard measurement produced differing analog voltage readings. Random error indicates a lack of repeatability or background noise affecting the measured values. The deviation plot in Figure 5 similarly shows this as the true distances have varying deviation across the trial measurements.

Conclusion

The designed measurement system was successful with the task of displaying the displacement of an object based on voltage readings of a potentiometer. It can be confidently stated that this device will quantify the size of a sample with an accuracy of ±0.13 inches to account for systematic/random error. For future considerations it is recommended to choose a potentiometer design that can attach to the pinion with greater ease. Using a potentiometer with a keyway would allow for the gear to be easily fixed and guarantee an accurate rotation measurement.