Summary of Design and Construction

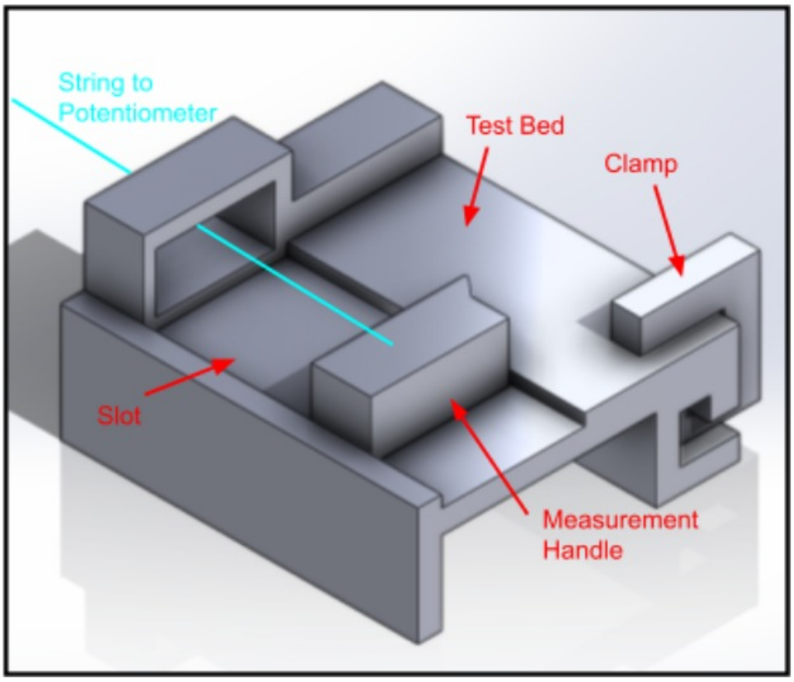

Figure 1: CAD Model of the Sensor's Design

The measurement device is operated by fixing the object to be measured using the clamp. The handle is then pulled outwards and aligned with the clamp. One end of a string is attached to the handle, and the other to a popsicle stick inserted into the potentiometer's dial. As the handle is pulled, the tension in the stick causes both the popsicle stick and the dial to rotate. The process of measuring a brick is shown in Figure 2.

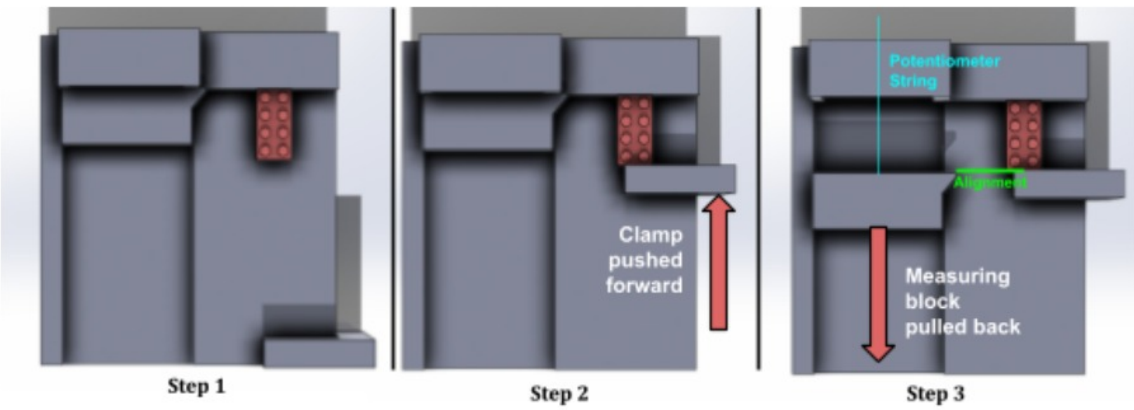

Figure 2: The Process of Measurement

Sensor Details and Measurement

The sensor in this system is the sliding contact coil of the potentiometer. The sliding contact changes the resistance of the potentiometer proportionally to the rotation of the dial. The signal modification system is the measured analog signal from the potentiometer found using an Arduino. The analog signal is a value that ranges from 0 to 1023, as the analogRead() function used in the code has a 10-bit resolution. This signal is converted to distance using the calibration equation. The indicator of the measurement system was the Arduino's serial monitor, which displays the calculated distance for the user.

Assumptions

The design is intended to measure accurately for distances up to 10 cm, but may involve error as the dimensions increase. Due to the limited range of the popsicle stick, it cannot keep the string in tension if it rotates beyond 180 degrees. Therefore, it is assumed that the Lego blocks fit within the range of the popsicle stick's rotation. Additionally, all of the tension in the string is assumed to be translated to rotation in the dial. However, there will be small amounts of error because the potentiometer cannot perfectly align with the string as it is pulled.

Calibration Procedure and Results

The calibration process involved selecting multiple different objects of varying lengths to test the accuracy of the device. The true length of each object was measured using a vernier calliper. Then, the object was measured using the device, which displays the potentiometer signal on the serial monitor. This process was repeated 13 times for each object to ensure consistent readings for each object. The lengths that were tested ranged from 14.9mm to 95.8 mm. This length range was selected to ensure the device can be used to measure any combination of the three Lego blocks. The results of the calibration are shown in Table 1.

Table 1: Calibration Data

True Distance (mm)	**Measured output**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
14.9	10	10	7	8	9	11	6	9	8	9	8	9	8
15.8	8	6	8	8	9	8	9	7	8	6	9	7	9
28.9	70	74	68	70	68	69	71	72	72	70	71	72	69
31.8	85	82	80	81	83	83	80	84	80	80	82	80	80
53.9	170	173	177	175	173	171	174	175	175	173	172	170	170
63.8	211	214	206	212	207	213	211	210	211	212	213	213	212
69.6	243	244	245	243	242	241	245	246	245	245	242	243	242
80.9	283	282	281	283	279	284	284	282	280	283	284	282	279
85.4	316	316	317	311	316	313	312	313	313	310	313	317	311
95.8	358	356	356	357	359	357	356	360	356	358	356	356	355

After determining the true length of the objects and collecting the potentiometer signal values, the true values [mm] vs. the measured values [potentiometer signal] were plotted on a graph (Figure 3).

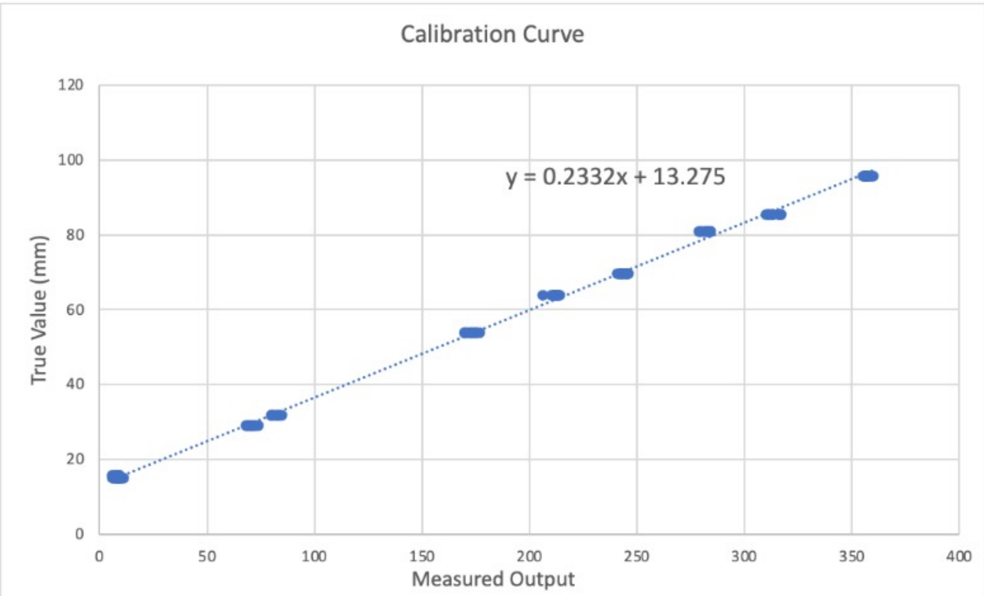

Figure 3: True values (mm) vs. Measured values

An equation for the linear line of best fit for the plotted data was found using Excel. This equation was then used to convert the signal values obtained by the device to a measurement in millimetres.

Deviation and Uncertainty Analysis

The measured values from the device were also used to determine the deviations from the true measurements. The deviation is calculated by subtracting the measured value from the true value. The deviations were then plotted against the true measured values to form the deviation plot in Figure 4.

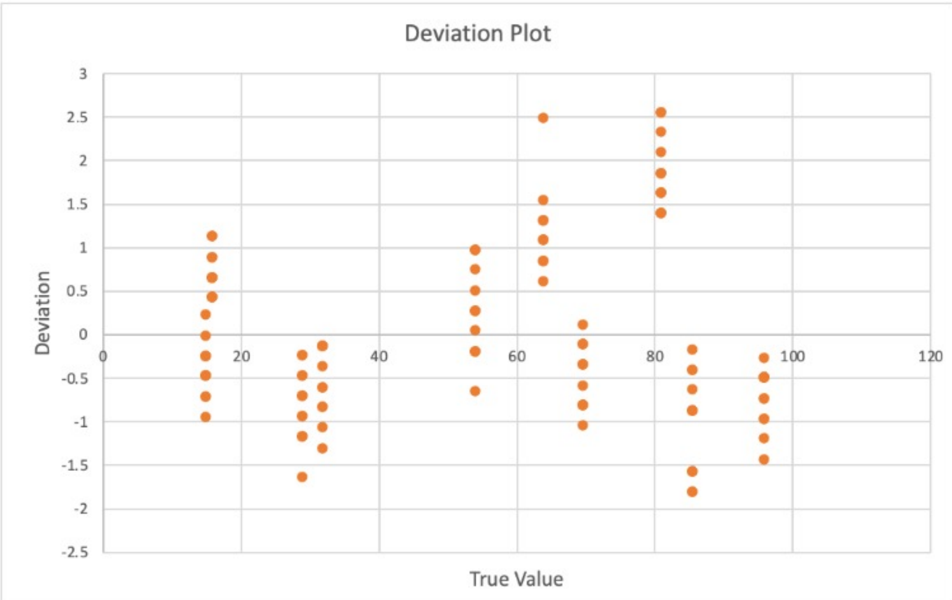

Figure 4: Deviation Plot

By analyzing the deviation plot in Figure 2, the maximum positive uncertainty is 2.56 mm and the maximum negative uncertainty is -1.8 mm. The differences in deviation for repeat tests suggest the presence of random error. A possible source of random error is the speed at which the handle is pulled, as moving the handle too fast would result in larger values being outputted. However, the speed cannot be kept consistent, resulting in random error. Another source of error is the result of how accurately the handle was lined up with the edge of the object. The handle was stopped once it reached the end of the object, but accuracy is dependent on the experimenter's judgement, resulting in random error in the trials. Additionally, by analyzing patterns in the data, it is evident that there is also some systematic error present. A possible source of this could be the tension in the string. After a few sets of measurements, the string connecting the potentiometer and the handle had stretched, resulting in some constant deviation in the output.

Conclusion and Recommendations for Future Work

The objective of the project was to design a measurement device which could determine the length of a given object. The device used a measurement handle attached by string to a potentiometer. The handle was pulled to measure and the value in millimeters was displayed on a monitor. A calibration procedure was implemented where objects of varying lengths were measured and were then used to find uncertainty and to construct a deviation plot (Figure 4). The results showed a positive uncertainty of 2.56mm and a negative uncertainty of -1.8mm. Possible sources of error included inconsistencies with the speed at which the measurement handle was pulled, the inaccuracy of alignment of the handle, and the varying tension in the string.

The first recommendation for future work is to improve the lever system for the string. The current design does not ensure that the string remains fully taut for the duration of the measurement, thus resulting in a source of error. An improvement is to have the spool mounted on the potentiometer which allows for better rotation and tension in the string.

Another recommendation is to improve the method by which the handle pulls on the string. Having a person pull the handle results in random error as the speed and alignment of the handle varies. Instead, a motor can be used to pull the string at a constant speed. This would eliminate any random error arising from the varying speeds with which the handle is pulled.

Appendix A - Arduino Program

```
int const potpin = A0;
float potval = 0;
float dist;

void setup() {
  // put your setup code here, to run once:
    Serial.begin(9600);
}

void loop() {
  // put your main code here, to run repeatedly:
  potval = analogRead(potpin); //read the potentiometer signal
  dist = 0.2309*(1023-potval)+13.329; //calculate the distance
  Serial.print(dist); // print distance
  Serial.println(" mm");

  delay(20);
}
```

Appendix B - Additional Photos of the Device