MTE 201 - Measurement Project Report

Brendan Chharawala, Eidan Erlich, Owen Moogk, Shabd Gupta

Design:

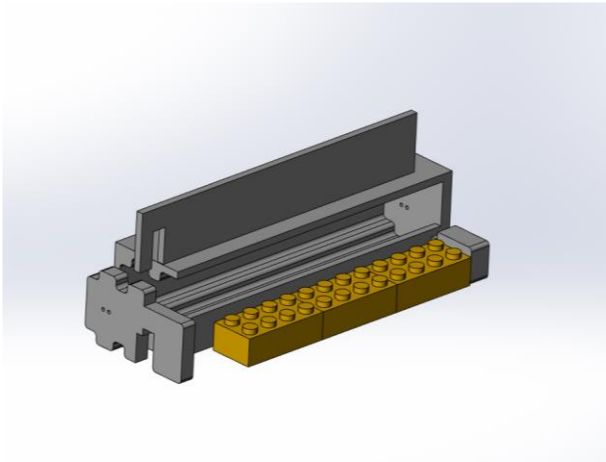
Our group developed a measurement system that uses a photoresistor and an LED, positioned at opposing ends of a light-insulated rod. It can gauge distances within the range of 0.5–10 cm by discerning variations in light intensity, which occur as the sample moves closer to or farther away from the photoresistor. The LED is attached to a sliding mechanism that clamps onto an object to measure the distance. This light-insulated system is designed to effectively limit external light interference and absorb internal light reflections, ensuring the precision of the measurements.

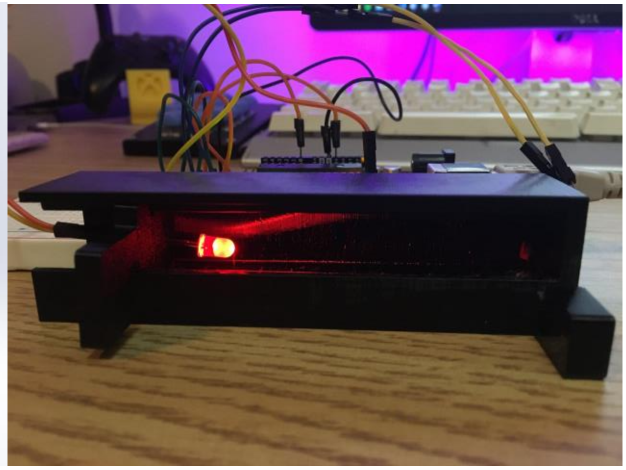
The sensor is the photoresistor at the fixed end of the tube. The signal modification system is the photoresistor circuit, converting the resistance to a voltage, which is then converted to a digital number using Arduino's analog-to-digital converter. The indicator is an output on a computer screen, that takes the serial value from the Arduino and converts it using the calibrated equation. This distance value is then shown on a computer monitor, indicating the measured data to the user.

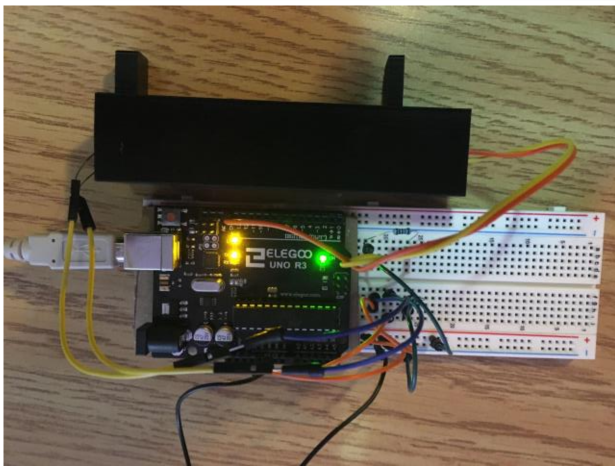
Construction:

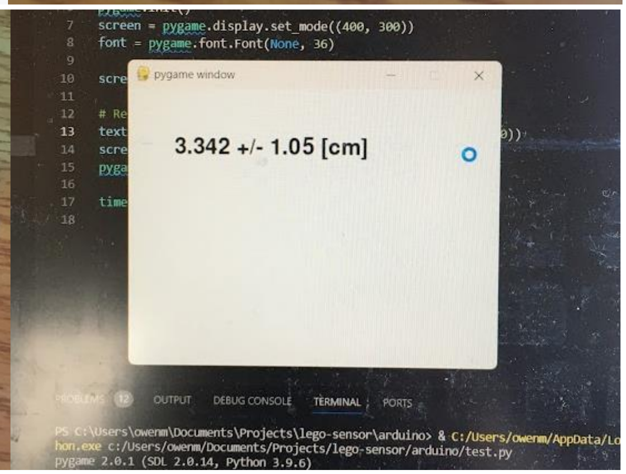
For the construction of the sensor, we used a 3D printer, an Arduino microcontroller, a photoresistor, an LED, and various resistors. The photoresistor is wired in a series circuit, and the voltage across the photoresistor is measured using the analog input pin of the Arduino. The measurement system is housed in a custom-printed PETG case. The design was made to be easily assembled and to require minimal post-processing work to function.

Photos of the design are shown below:









Theory of Operation:

The theory that a photoresistor’s resistance changes relative to the perceived light intensity forms the basis of the measurement system. When the distance between the LED and the photoresistor changes, the effective resistance value of the photoresistor also changes. A voltage divider is used to measure the change in resistance. Calibration analysis is performed to estimate the distance that the emitter is from the receiver.

Assumptions:

The group made a few assumptions in the design of the measurement system.

It was assumed that the LED would have a consistent light intensity without flickering and that external light interference that could bleed through our case would have a negligible impact on the system. If the LED did flicker during operation, it is assumed to be consistent and would therefore be accounted for in the calibration analysis, however, we did not observe this. Both of these effects seemed to have negligible impacts on our system and can be assumed to be non-existent.

Additionally, it is assumed that continuous use of the system will not affect the LED's intensity or the sensor's reactivity. Note that with long-term use of the system, the intensity of the LED and reactivity of the photoresistor may need to be accounted for to maintain accuracy.

Moreover, wear and tear on the mechanical system may decrease precision, this error is assumed to be negligible.

Lastly, it is assumed that the rounding due to the Arduino's analog-to-digital converter will have a negligible effect on the precision of the sensor. In the system, the analog voltage value is converted to a digital signal between 0 and 1023, reducing the precision of the system. It is assumed that the rounding is negligible.

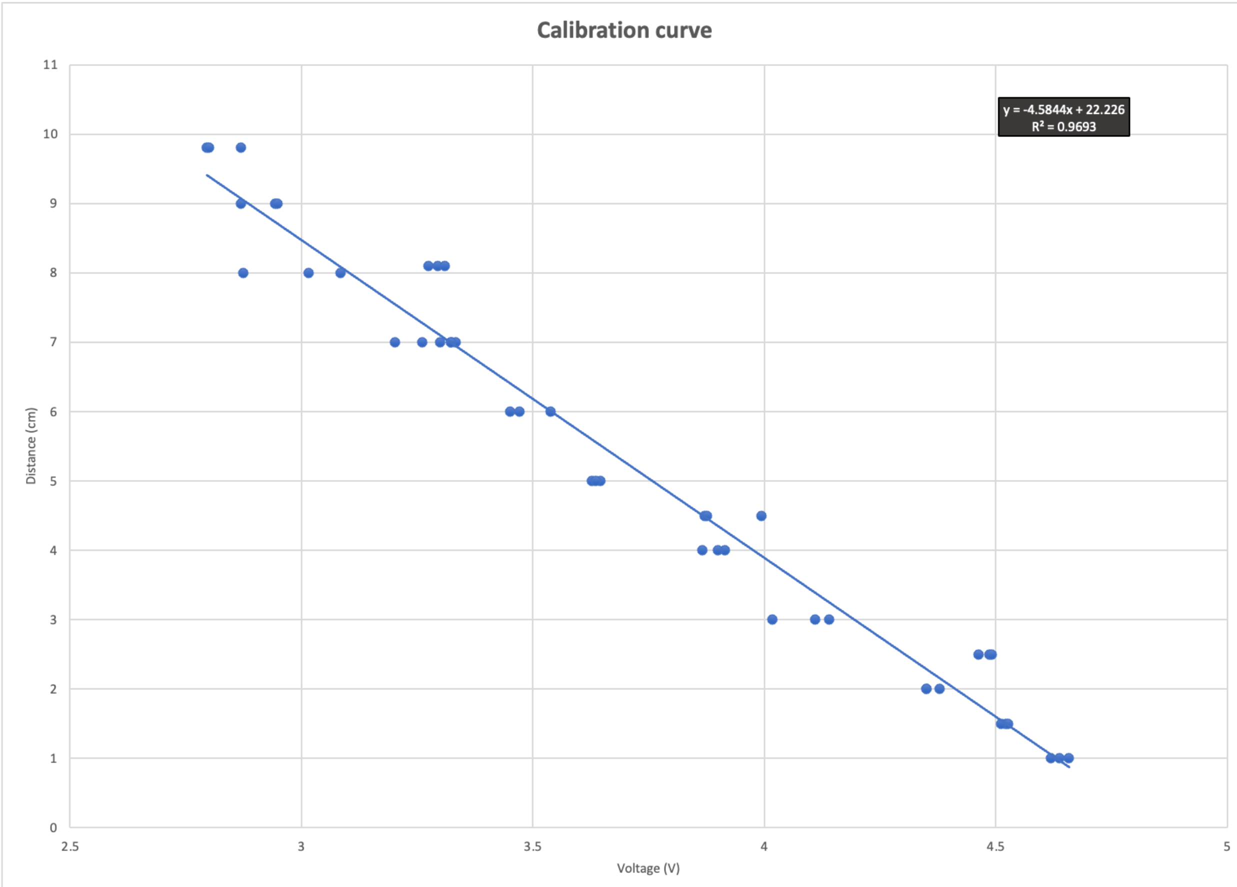
Results:

Calibration:

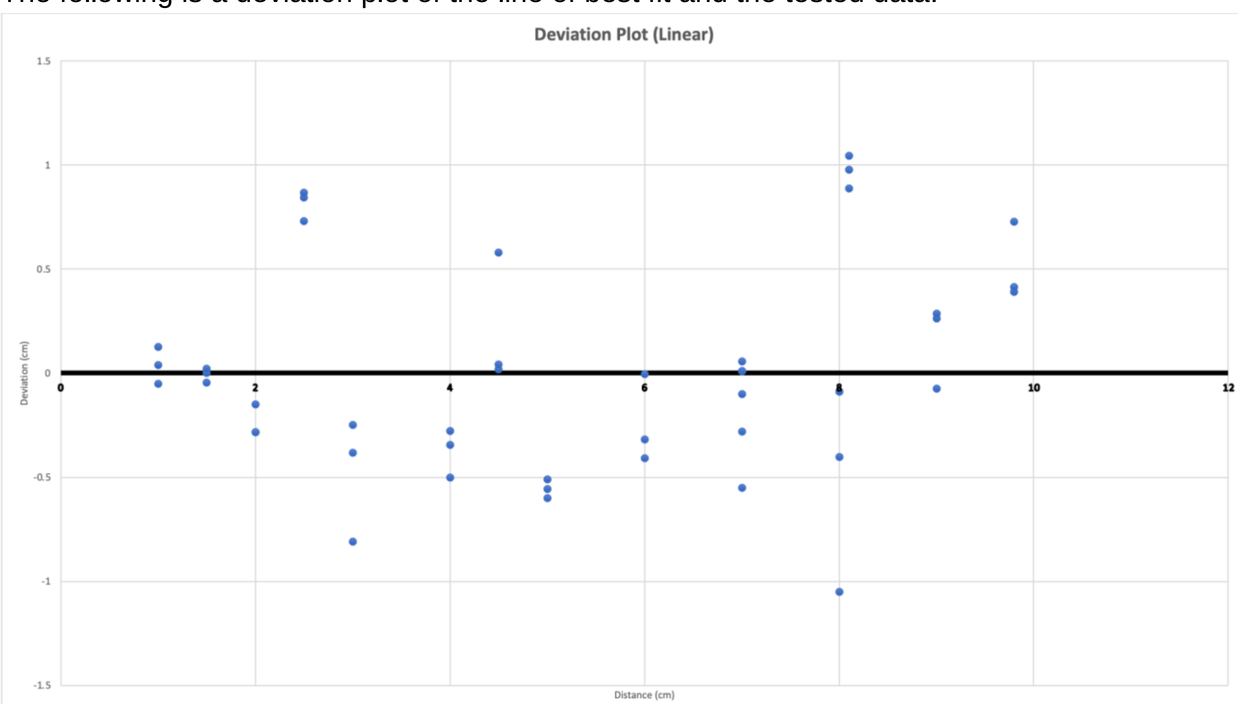
The measurement device is calibrated using a vernier calliper. For each incremental distance within the operating range, readings are recorded by the device, and the ground truth distance is established with the vernier calliper. This iterative process is conducted until a sufficient dataset is accumulated, covering the measurement bounds. After data collection, four distinct curve-fitting techniques were applied to the dataset: a linear fit, a third-degree polynomial curve, a logarithmic curve, and an exponential curve. Each curve undergoes uncertainty analysis to identify the optimal fit. The linear line of best fit was determined to be the most suitable fit within the operational range of the measurement device.

Calibration Data and Curve:

The following chart is the calibration curve of the output voltage of the sensor v.s. The distance of the sample.



The following is a deviation plot of the line of best fit and the tested data.



Sources of Error:

Upon analyzing the calibration curve and deviation plot, it is evident that both systematic and random errors are present in the system. The random error appears to be amplified at greater distances, whereas the system exhibits greater accuracy at smaller distances. The recorded errors in the conducted tests were found to have a range of +1.04 to -1.05 cm.

Systematic errors within the measurement system could be attributed to discrepancies in the construction and alignment of the photoresistor. A slight change in the angle of the photoresistor could impact the perceived light intensity and, therefore, the voltage change across it. Additionally, the reflective properties of the internal housing and the intensity of the LED may have introduced variability in the measurements. These were accounted for as best as possible during the calibration process, however, there are still minimal effects left in the result.

Another potential source of systematic error can be tied to the resolution limitations of the Arduino's analog pin readings. The Arduino's capability to discern voltage differences is constrained to increments of 1024 within the 0–5000 mV range. Improving the resolution of the readings entails a modified voltage divider circuit and an alternative power source and expanding the operating voltage range of the system.

Conclusion:

In summary, the measurement system performed well within the 1 to 10 cm range, with an approximate uncertainty of 10% full scale. Based on the calibration data, the uncertainty was found to be +1.04 cm and -1.05 cm.

To improve the precision of the measurement system, a viable solution is to replace the current red LED with a green LED. The red LED's wavelength is roughly 680 nm, while the green LED emits light at approximately 540 nm. Leveraging the properties of the photoresistor, the relative spectral response change due to the wavelength of the perceived light would nearly double with the use of a green LED. The precision is anticipated to proportionally increase with the change.

Another potential enhancement involves modifying the voltage divider to extend the operating range of the Arduino. The system has an input voltage range of 0 to 5 volts. By reconfiguring the circuit to work on a larger voltage range, the precision of the system could be increased.