3L04 Lab 5 – Photosensors & PWM

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Abstract

The purpose of this lab is to explore the functionality and limits of two types of optical detectors: a photoresistor and an Infrared Sensor. The photoresistor is first subjected to an LED light source at 1 cm intervals from a separation of 0 cm to 30 cm. After completing and processing the data from 5 separation trials using this methodology, a clear representation of the squared relationship between resistance and separation distance ($R = Ad^2$, where A is a proportionality constant) is observed. Subsequently, the infrared sensor is subjected to a infrared remote control to assess the maximum distance at which it can detect infrared rays. From there, three objects are introduced in an attempt to obstruct the incoming ray: a pair of sunglasses, a sticky note, and a textured drinking glass. Each obstruction trial is carried out to assess the maximum distance at which the sensor can pick up an incoming infrared signal with the respective object introduced. This experiment shows obstructions diminish the ability of the sensor to detect rays, and reveals the efficacy of glass treatment, surface irregularities, and opacity for blocking infrared rays. The final experiment in this lab revisits the photoresistor to assess its behaviour when subject to a light source controlled by automated pulse width modulation. The pulse width modulation properties of the light source are first tested manually using a rotary encoder before the photoresistor is aligned with the light source. This experiment demonstrates an expected modulated signal reception and adequate photoresistor sensitivity. The discussion section of this report includes a review of the working principles of each device and the implications of the aforementioned results.

Results

Photoresistor

To experiment with the functionality of the provided photoresistor, both the sensor module and a 30 cm measuring tape were affixed to a flat desk, shown in Figures 1 and 2.

Figure 1 Measuring Tape and Aligned Photoresistor

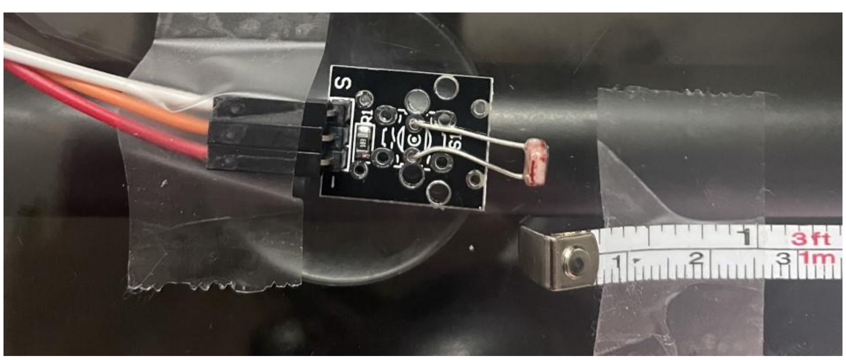

Figure 2 Photoresistor at 0 cm

Using this arrangement, an LED flash (installed in an iPhone) was used to introduce a light source to the photoresistor at 1 cm increments along the 30 cm measuring tape. Deliberate effort was made to maintain a consistent alignment between the source and sensor as the distance was varied. To minimize the change of undesired light interacting with the system, the sensor was sheltered as shown in Figure 3.

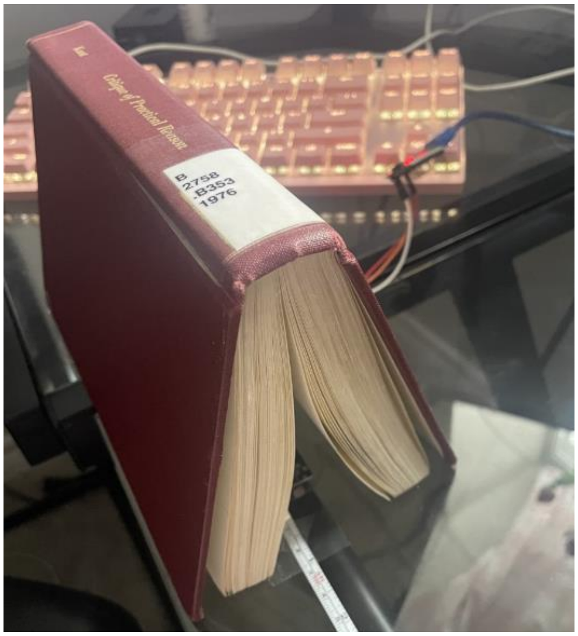

Figure 3 Sheltered Photoresistor

To achieve legible results, the source was held at each 1 cm mark for 5 seconds before being moved to the next whole maker. This was done by hand, which may introduce some uncertainty in the actual distances, increments, and time intervals. To account for this potential uncertainty, the procedure was carried out a total of 5 times. The results are plotted accordingly in Figure 4. It should be noted that error bars were omitted from this plot for legibility, but the presented data should be interpreted with an x-uncertainty of $\pm$ 0.05 cm and a y-uncertainty of $\pm$ 1% [1].

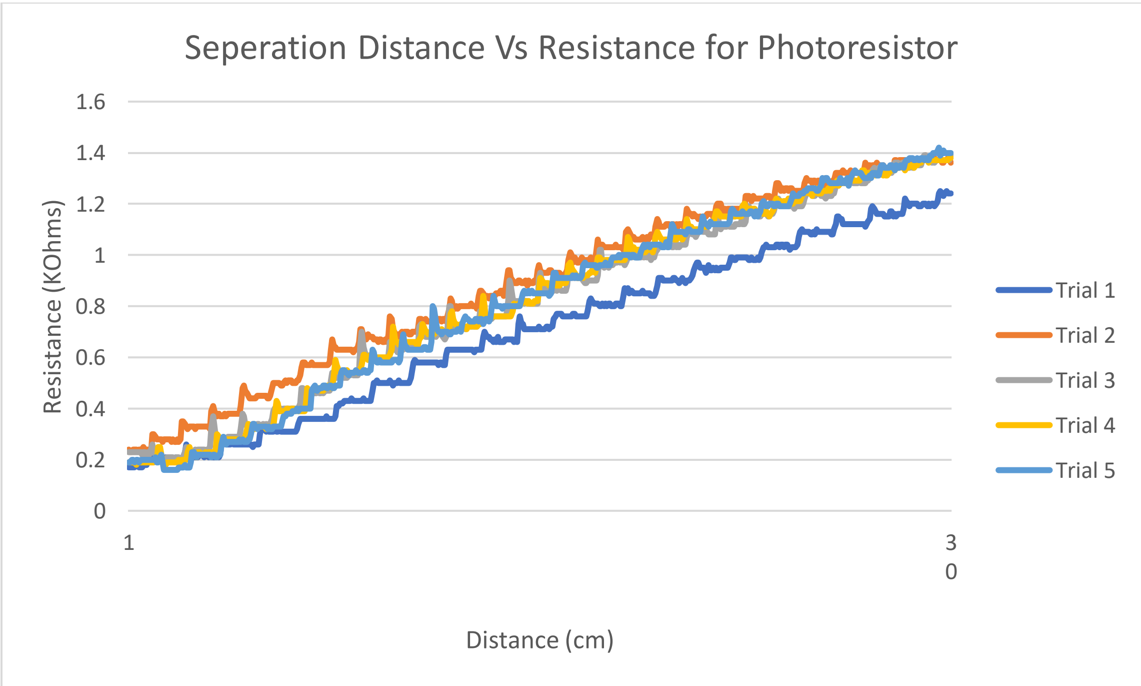

Figure 4 Photoresistor Results

As seen, resistance and separation distance share very linear relationships. Since this result showcases the trend over hundreds of data points, a more simplified and point specific result will be shown in the discussion section of this report.

Infrared (IR) Sensor

To assess the functionality of the IR sensor, the device was connected to the Arduino as instructed and affixed to the desk at the 0 cm mark of the same tape used in Figure 1. To interact with the sensor, an IR remote control was used, shown in Figure 5.

Figure 5 IR Sensor Set-Up

The first trial of this experiment was carried out with no obstruction to the IR sensor. Since the experiment took place in a basement on a cloudy, there was little concern for unwanted IR waves interacting with the device. Thus, the remote was activated and dragged along the desk surface until the LED no longer indicated sensing. After collecting this maximum value, three obstructions were sequentially introduced to the system: sunglasses, a sticky note, and a textured drinking glass.

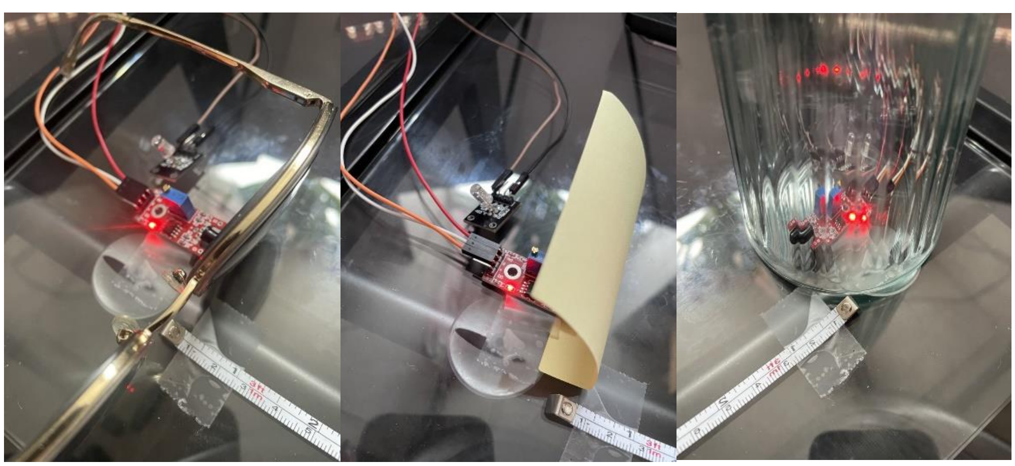

Figure 6 IR Obstruction Trials

The quantitative results from the 4 trials are shown below.

Table 1 IR Sensor Trial Results

Obstruction	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Trial 4 (cm)	Trial 5 (cm)	Average (cm)	Standard Deviation
-	126.2	122.8	124.2	119.9	122.6	123.1	2.068
Sunglasses	47.6	51.1	50	51	49.7	49.9	1.264
Paper	17.5	18	18.3	18.7	18.3	18.2	0.398
Glass	76.1	75.5	74.9	75.6	75.9	75.6	0.41

Qualitatively, each of the obstructions diminished the maximum sensing distance of the sensor. An in-depth discussion of each material used will follow in the Discussion section of this report.

Digital Dimmer with Pulse Wave Modulation

For the first half of this experiment stage, a rotary encoder and LED were attached to the Arduino. With reference to the initial state of the rotary encoder (ie. its position when the script was sketched to the Arduino), it was observed that the light emitted from the LED would intensify with a clockwise turn and lessen with a counterclockwise turn. The fluctuations and overall intensity of this light were very minute, but this behaviour indicated successful implementation of the Pulse Wave Modulation (PWM) method, which will be further explored in the Discussion section of this report.

The second half of this experiment entailed reinstalling the photoresistor and affixing it to the table such that it remained facing the LED with a separation distance of approximately 5 cm, shown in Figure 7.

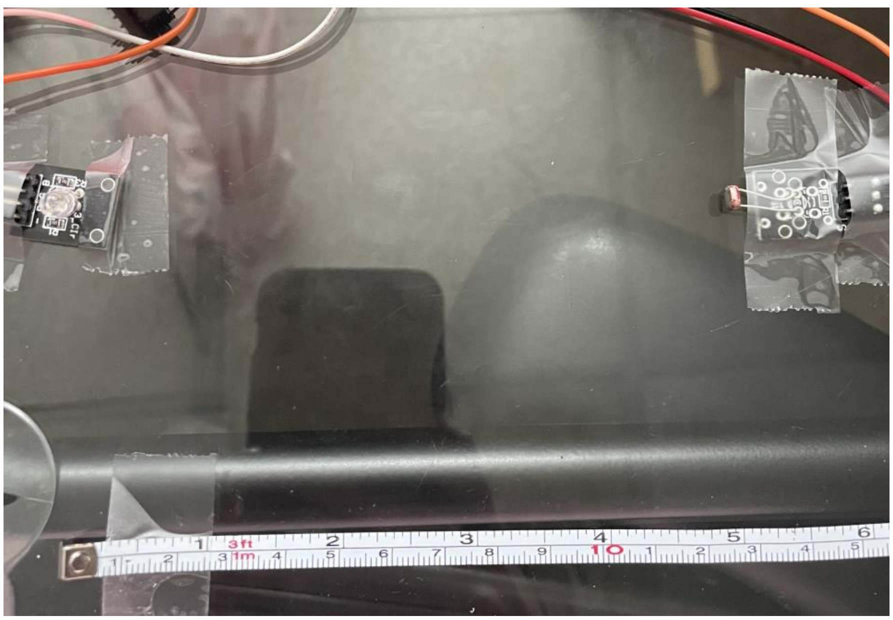

Figure 7 Photoresistor and LED

Using the serial plotter in the Arduino environment, the resistance behaviour of the photoresistor was monitored while the LED was subjected to an automatically fluctuating PWM. The behaviour was quite varied, but the data shape shown in Figure 8 was repeatedly displayed as time went on. Though this shape alone does not allow for rigorous analysis of the system behaviour and uncertainty, it is sufficient for the qualitative analysis prompted by the requirements of this lab exercise.

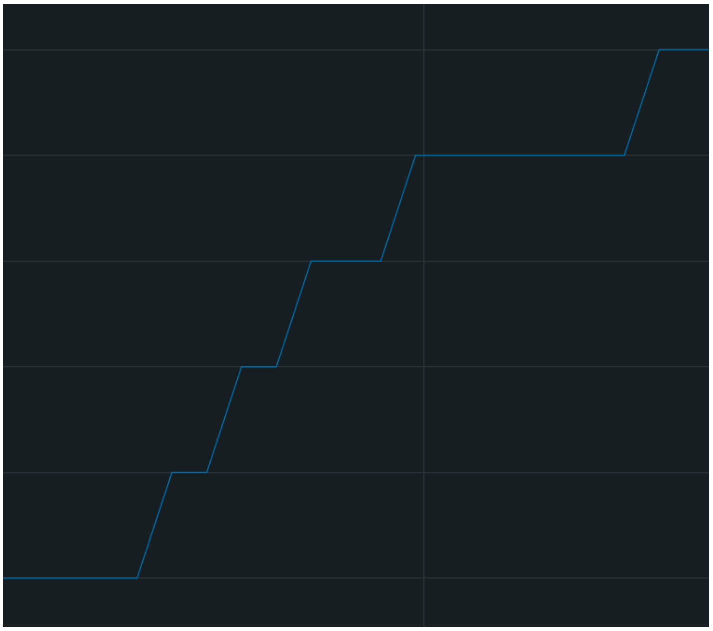

Figure 8 Photoresistor Behaviour in Response to PWM LED Emissions

Discussion

Photoresistor

Photoresistors are optical sensors that implement light-sensitive resistors to measure light intensity. The working principle of these devices correlate to an inverse proportionality between light intensity and resistance (ie. a high intensity light source will result in a lower resistance value) [2]. This is validated the following relationship for a photoresistor.

$$R_{ph} = \frac{A}{I} \quad [2]$$

Where A is a proporationality constant and I is the light intensity.

Photoresistors are typically fabricated from high resistance semiconductor materials, such as silicon [3]. When these materials absorb light, they exhibit desirable electron-hole pair formation that enables the above relationship. When an intense light source (ie. a high energy source) is introduced to a photoresistor material, a large amount of energy is absorbed and, as a result, a large amount of valence electrons jump into the material's conduction band. This tendency toward conduction thus reduces the resistance of the material. Less electrons will reach the conduction band as less energy is introduced, thus maintaining the expected effect [3].

1. As mentioned in the Result section of this report, data was collected in 1 cm intervals every 5 seconds. To truncate this data for more accurate processing, the average of each 5 second interval was found to represent the value of that trial at the corresponding distance. From there, the 5 data sets were easily compared to deduce average values and explore the standard deviation of the experiment. The numerical results of this process are shown in Table 2.

Table 2 Processed Photoresistor Results

Distance (cm)	Trial 1 (kOhms)	Trial 2 (kOhms)	Trial 3 (kOhms)	Trial 4 (kOhms)	Trial 5 (kOhms)	Average Resistance (kOhms)	Standard Deviation
1	0.17	0.24	0.22	0.19	0.2	0.2	0.03
2	0.2	0.29	0.22	0.2	0.21	0.22	0.04

3	0.22	0.33	0.23	0.23	0.23	0.25	0.05
4	0.26	0.38	0.29	0.28	0.28	0.3	0.05
5	0.32	0.45	0.33	0.33	0.33	0.35	0.05
6	0.36	0.57	0.46	0.48	0.4	0.45	0.08
7	0.41	0.63	0.52	0.57	0.49	0.52	0.08
8	0.43	0.63	0.53	0.54	0.53	0.53	0.07
9	0.5	0.67	0.59	0.6	0.62	0.6	0.06
10	0.58	0.7	0.64	0.66	0.63	0.64	0.04
11	0.63	0.74	0.68	0.7	0.69	0.69	0.04
12	0.68	0.84	0.76	0.75	0.75	0.76	0.06
13	0.71	0.89	0.82	0.82	0.85	0.82	0.07
14	0.76	0.93	0.87	0.89	0.93	0.88	0.07
15	0.82	0.98	0.9	0.93	0.96	0.92	0.06
16	0.86	1.09	0.97	1	1	0.98	0.08
17	0.91	1.13	1.03	1.08	1.04	1.04	0.08
18	0.94	1.16	1.1	1.11	1.1	1.08	0.08
19	0.99	1.18	1.12	1.16	1.16	1.12	0.08
20	1.03	1.22	1.16	1.22	1.2	1.17	0.08
21	1.09	1.29	1.24	1.24	1.26	1.22	0.08
22	1.12	1.32	1.29	1.28	1.28	1.26	0.08
23	1.16	1.34	1.33	1.32	1.33	1.3	0.08
24	1.2	1.38	1.36	1.37	1.4	1.34	0.08
25	1.24	1.4	1.37	1.37	1.4	1.36	0.07
26	1.27	1.44	1.4	1.4	1.43	1.39	0.07
27	1.3	1.46	1.42	1.41	1.46	1.41	0.07
28	1.33	1.49	1.45	1.44	1.48	1.44	0.06
29	1.37	1.53	1.5	1.48	1.5	1.48	0.06
30	1.42	1.54	1.52	1.48	1.51	1.49	0.05

Using this data, the plot in Figure 9 was obtained. Though they are not visible, an error of $\pm$ 0.05 cm is included for all distance values (ie. half of the smallest unit of measurement on the measuring tape). The resistance error bars included represent the respective standard deviation values.

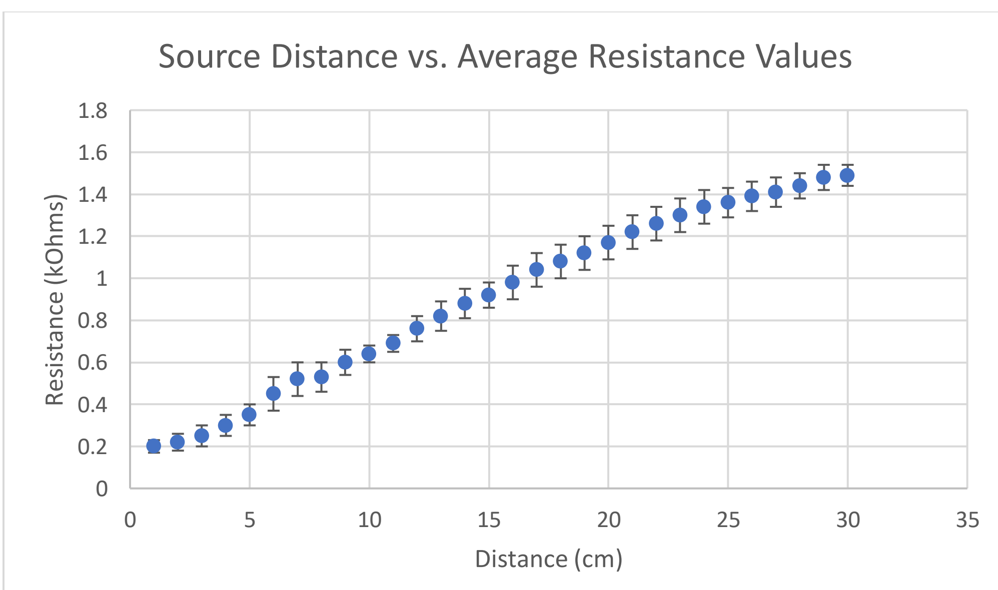

Figure 9 Processed Photoresistor Results

2. Using the same plot, the trendline shown in Figure 10 can be added.

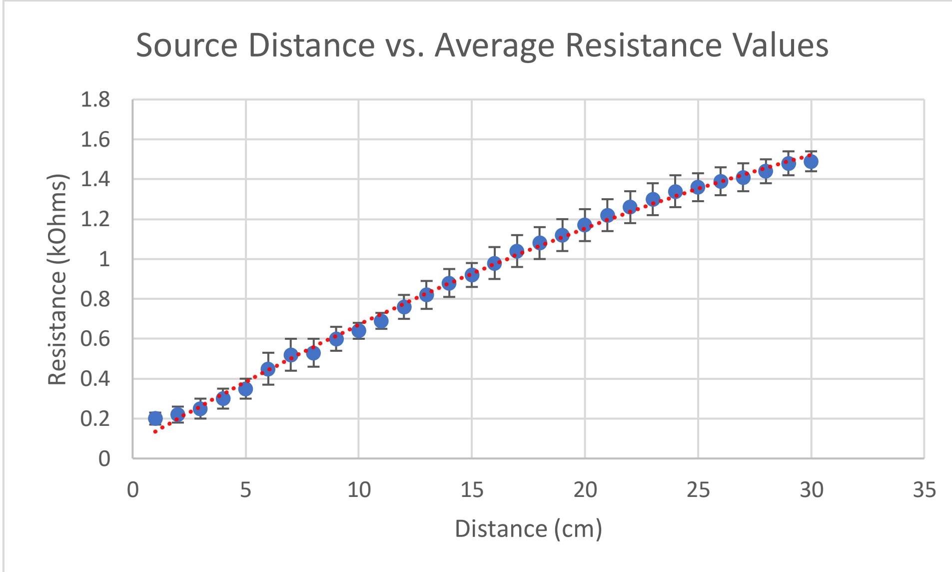

Figure 10 Processed Photoresistor Results with Trendline

Though this may appear line a linear relationship at first glance, the trendline of best fit is a quadratic. Qualitatively, the increasing relationship between resistance and distance makes sense. Since the resistance is inversely proportional to intensity, increasing the separation between the source and sensor should increase the resistance. This can be explained quantitatively using the inverse square law, which states $I = \frac{1}{d^2}$, where I is the light intensity and d is the separation [3]. Using the relationship stated before, resistance can be written in terms of d via $R = Ad^2$. This explains the quadratic best fit. The negative nature of the polynomial is likely due to the proportionality constant inherent to this device and does not violate the presented logic.

Infrared (IR) Sensor

IR sensors are devices specialized to detect light with wavelengths falling between 780 nm and 1 mm. This range can be further divided into the near-infrared (0.75 μm to 3 μm), mid-infrared (3 μm to 6 μm), and far-infrared (> 6 μm) regions [4], though sources tend to disagree on the exact intervals assigned to each region. IR sensors come in two forms: active and passive. Active IR sensors implement RADAR technologies to emit and receive IR light [4]. This system is ideal for proximity sensors, since the sensor will only receive light that has been reflected off of a surface, allowing the time between emission and reception to be interpreted as distance [4]. Passive IR sensors only receive IR light, simply detecting if IR light is present [4]. The sensor employed in this lab is passive.

IR light tends to experience exponential decay between intensity and separation distance. Since passive IR sensors are typically very sensitive, they tend to accurately sense the presence of IR light until the intensity has completely diminished [4].

1. When unobstructed, the maximum sensitivity of the IR sensor was found to be 123.1 cm with a standard deviation of 2.1. It was expected that, but introducing obstructions, the value would diminish. Each obstruction was selected to test a different theory on how to best block IR light from interacting with the sensor. The sunglass lenses used in the first trial were both shaded and polarized. IR light interacts with polarized glass similarly to visible light, meaning all radiation that is perpendicular to the lens will be reflected [5]. Between this and the increased opacity compared to the unobstructed trial, it makes sense the maximum distance diminished as much as it did to a final value of 49.7 cm with a standard deviation of 1.3. The second trial implemented a

sticky note to add increased opacity to the light path. Opacity is generally defined based on the tendency of a material to allow visible light to travel through it. Since IR rays have longer wavelengths than the entirety of the visible light spectrum, traditionally opaque materials may allow IR radiation to pass through [6]. The sticky note used was not fully opaque, but it did demonstrate the most notable obstruction with a final maximum distance of 18.2 cm with a standard deviation of 0.40. The final trial implemented a textured drinking glass. This was chosen since the textured surface should, in theory, cause scattering and diminish the rays that reach the sensor. Since the maximum distance was diminished to 75.6 cm with a standard deviation of 0.41, it can be safely assumed that this did take place. Comparing to the other obstruction trials, though, it is far from the most effective method.

Existing IR blockers typically employ several methods to increase the likelihood of scattering and complete absorption. Low-emissive glass, for example, is specifically designed to reflect IR rays using thin film coatings while still allowing sunlight to pass through [7]. Etching surface – or otherwise creating irregularities in a surface – is also effective to reflect IR rays since it increases the likelihood of a ray being reflected [8]. With these technologies in mind, the obstructors used in this lab each employed a partially correct method. Combining the polarization of the sunglasses, the opacity of the sticky note, and the irregularity of the drinking glass would likely result in a highly diminished IR transmission rate.

2. Infrared and ultrasonic sensors implemented in object detection both implement the active sensing principles outlined above. The main difference between the two technologies, of course, is the type of wave they emit or receive, namely light or sound. The main discrepancies that dictate the applications of each technology lie in the accuracy and ease of implementation of each. Ultrasonic sensors (which implement sound waves to carry out an emission-reception process called echolocation) are typically much more capable of relaying the precise location of an object due to the larger size of sound waves, as shown in Figure 11. Ultrasonic sensors are also able to detect materials with a larger range of opacities and structures than IR sensors, since ultrasonic sound is easily reflected [9]. Ultrasonic sensors are often relatively unaffected by environmental inference like light, smoke, and air particles. This further increases the applications in which an ultrasonic sensor can be implemented [9]. When it comes to simple object detection, however, IR sensors are ideal since they are much easier to implement. Generating IR rays requires less moving parts and less mechanical intricacy than ultrasonic waves. This makes both the manufacturing and maintenance process of IR devices much easier and cheaper.

   In the context of autonomous vehicles, I can see each being implemented in its own scenario. For emergency overrides, breaking, and collision avoidance, I would select an IR sensor. For these applications, distance accuracy and auxiliary scanning are less important than simply knowing an obstacle exists. For applications of computer vision, traffic navigation, and more general decision-making, however, I would absolutely choose an ultrasonic sensor for its large range of detection, material diversity, and overall sensitivity.

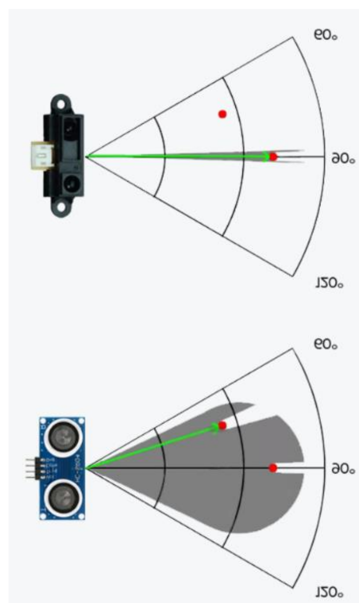

Figure 11 IR vs Ultrasound Ranges

Digital Dimmer with Pulse Wave Modulation

The theory behind the photoresistor is included in the Photoresistor section of this report. From Lab 2:

“Rotary encoders are devices that are used to measure angular displacement via the conversion of mechanical motion into electrical signals. There are optical and electronic versions of this device, and the Arduino ecosystem typically implements the electronic version. In this type of rotary encoder, two pins are affixed to a rotating base which is positioned above a second platform with sections of conductive materials, shown in Figure 1. When the shaft is rotated, the two pins will move incrementally, either contacting the conductive materials or not. This cause a square wave to be generated, with up/down triggers occurring with each change in signal (ie. whether or not the pin is in contact with the conductive material), which can be processed to determine the amount the shaft has been rotated. The waves generated by each of the pins will be approximately 90° out of phase. The processor can be configured to recognize which pin output is leading, which communicates whether the shaft is rotated clockwise or counterclockwise” [9].

1. Pulse width modulation (PWM) employs a digital signal to vary the power of an electrical signal. The principle of PWM is to alter the duty cycle (ie. the interval between high values) of a digital signal to periodically increase or decrease the power being delivered according to a desired trend. A higher duty cycle (ie. the signal is at the maximum value for a relatively longer time) will result in more power being delivered, and vice versa [10].
2. The plot in Figure 8 shows the photoresistor output while subject to a pulse wave modulated LED output. The trend shown adheres to what is expected for an automatically PWM controlled signal. The “step” nature of the signal indicates changes in duty cycles, with a step up correlating to a higher duty cycle and a step down equating to a lower duty cycle. Similar conclusions can be drawn from the first part of the experiment where the PWM was manually altered. When the rotary encoder was turned clockwise, the duty cycle was increased, and the intensity of the light increased as well. When the encoder turned the other way, the opposite happened, and intensity diminished.

References

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