Team 10:
Matthew Haahr (MH)
Brian Shin (BS)
Nick Hom (NH)

RBE 2002: Unified Robotics II—Lab 2: Velocity Control Post-Lab

Contribution Statement: MH. Wrote Code; MH, BS, NH. Collected and graphed data for individual robots; NH, BS. Written post-lab responses.
MH, BS, NH contributed equally to this work.

1. Ultrasonic readings and analysis
   a. Plots

Figure 1.1:

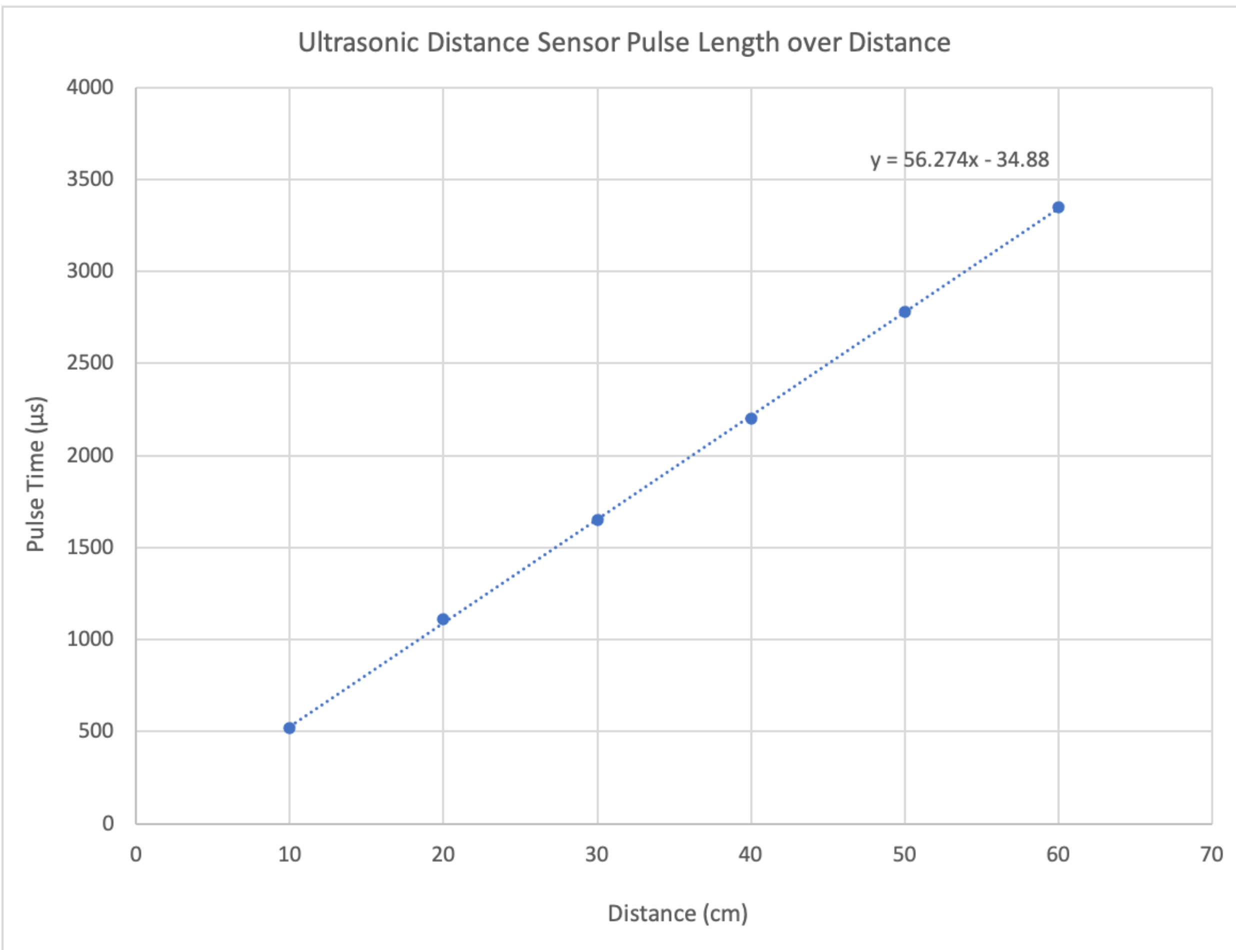

Figure 1.1: [Matthew] Ultrasonic Distance Sensor Pulse Length over Distance

Figure 1.2:

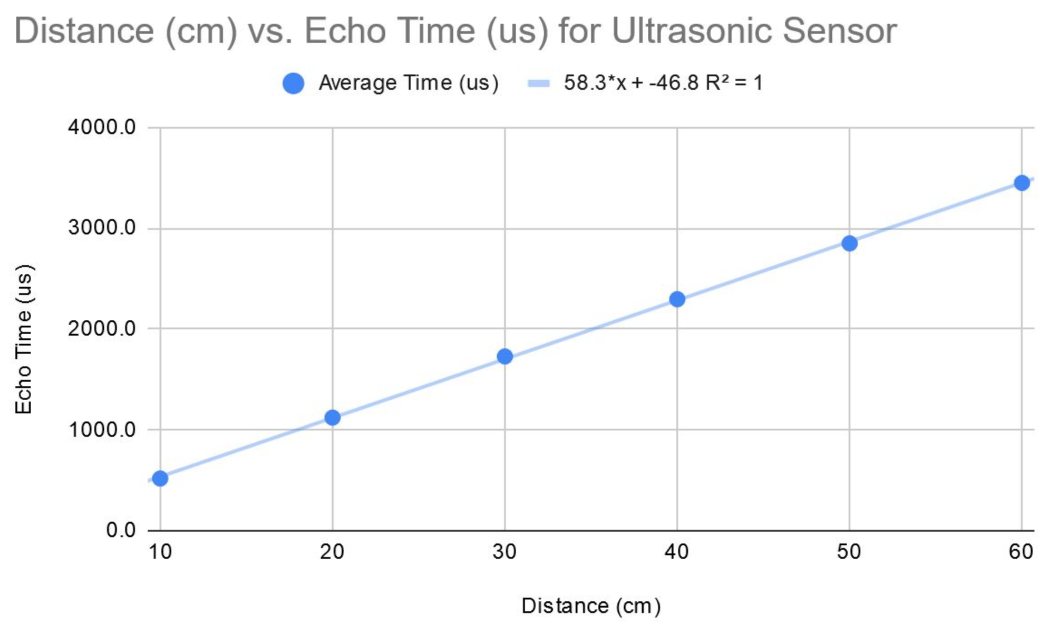

Figure 1.2: [Brian] Ultrasonic Distance Sensor Pulse Length over Distance

Figure 1.3:

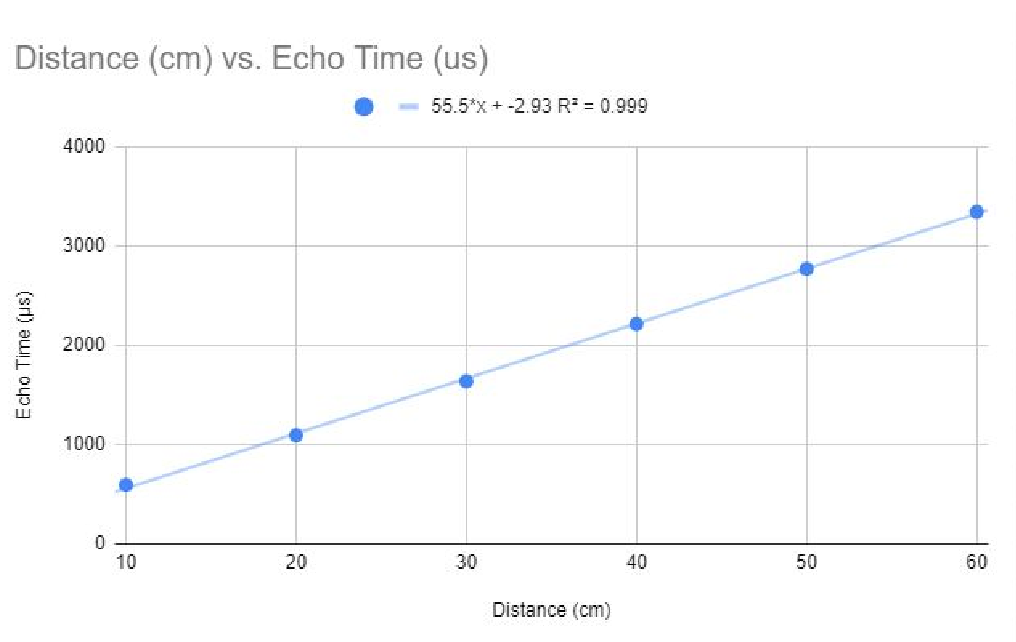

Figure 1.3: [Nick] Ultrasonic Distance Sensor Pulse Length over Distance

b. Do the sensor responses have a reasonably linear form?
    i. The average of 20 values per distance were very linear -- even the raw data was as well. Looking at the error between Average Pulse Lengths and Best Fits, the error is at least two orders of magnitude smaller than the Average (or Best Fit equation). Another indication of linearity can be seen in the correlation coefficient (r^2) of the linear regression, and a value closer to 1 indicates a linear form. As seen in Figure 1.2, the r^2 value is 1, which supports a linear relationship between echo time and distance.

2. Echo time averages
    a. Tables
        i. Matthew

Distance	Average Pulse Length (µs)	Standard Deviation (µs)	Best Fit $t = 56.274 * d - 34.88$ (µs)	Error (µs)
10 cm	521.2	9.9768	527.86	-6.66
20 cm	1110	7.6227	1090.6	19.4
30 cm	1647.2	8.5692	1653.34	-6.14
40 cm	2202.6	1.9574	2216.08	-13.48
50 cm	2779.8	12.4122	2778.82	0.98
60 cm	3347.4	7.2576	3341.56	5.84

        ii. Brian

Distance	Average Pulse Length (µs)	Standard Deviation (µs)	Best Fit $t = 58.3 * d - 46.8$ (µs)	Error (µs)
10 cm	518.0	2.052	536.2	-18.2
20 cm	1122.0	2.052	1119.2	2.8
30 cm	1728.8	1.642	1702.2	26.6
40 cm	2296.4	1.789	2285.2	11.2
50 cm	2849.8	2.042	2868.2	-18.4
60 cm	3449.5	5.463	3451.2	-1.7

iii. Nick

Distance	Average Pulse Length (μs)	Standard Deviation (μs)	Best Fit $t = 55.5 * d - 2.93$ (μs)	Error (μs)
10 cm	586.67	6.11	552.07	34.60
20 cm	1088.00	1.26	1107.07	-19.07
30 cm	1634.48	1.99	1662.07	-27.59
40 cm	2213.14	10.74	2217.07	-3.93
50 cm	2770.29	9.93	2772.07	-1.78
60 cm	3347.43	12.15	3327.07	20.36

3. Data comparisons between robots
    a. Errors
        i. The differences between each sensor can be seen in the errors across the three robots. Between Matt's sensor and Brian's sensor, we can see that the average error is higher on Brian's sensor, disregarding the direction of the error meaning Brian's sensor returns less linear values when compared to Matthew's. Nick's sensor has the worst error out of the three robots.

    b. Other
        i. Another thing to note is the standard deviation across the measurements -- Brian's sensor has a generally lower standard deviation than that of Matt's sensor, which can be a testament to the consistency and precision of each individual sensor.

4. Strengths and limitations of ultrasonic sensors
    a. Strengths
        i. Ultrasonic sensors are able to sense all kinds of material types. It has no preference over material reflectance or texture. Many other types of sensors rely on feedback from light which can be very difficult to automatically calibrate under different lighting conditions. This makes distance sensing possible in darker lighting conditions. (Helpful with night vision!)

ii. The range of these sensors are generally higher than those of inductive or capacitive sensors that rely on reading a specific type of object within close proximity.
iii. It is usually accurate with reading larger objects with hard surfaces. This makes this skype of sensor ideal for sensing stationary objects or surfaces such as walls, furniture, etc.

b. Limitations
   i. Ultrasonic sensors have no ability to distinguish object sizes. This makes sensing environments difficult when there are many objects in an enclosed space. If you are trying to look for a specific object, it is near impossible to do with this kind of sensor
   ii. If you are trying to create swarms of robots that utilize distance sensors, multiple ultrasonic sensors can't be used because they would pick up eachothers signal pings.
   iii. Because the sensor relies on sound, the atmospheric temperature can affect the expected performance of the sensor significantly. Different temperatures cause sound waves to travel differently. If a robot, for example, were to be collecting data at Mount Everest, the sensor readings for the same distance would be different at sea level and the summit.
   iv. Because of the way sound reflects, ultrasonic sensors struggle to detect objects at an angle as they do not receive the echo from the object.

5. IR sensor readings and analysis
   a. Plots

Figure 2.1:

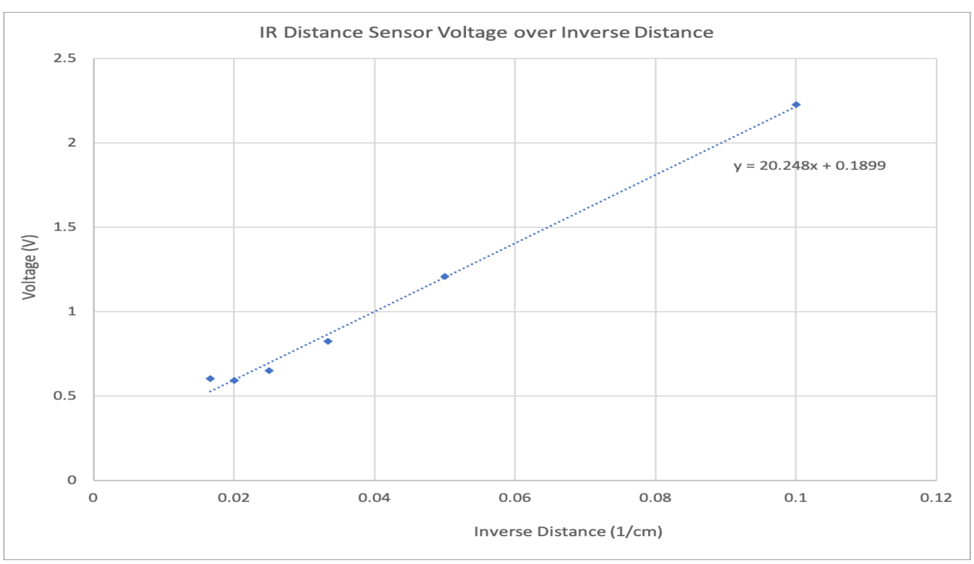

Figure 2.1: [Matthew] Infrared Distance Sensor Voltage over Inverse Distance

Figure 2.2:

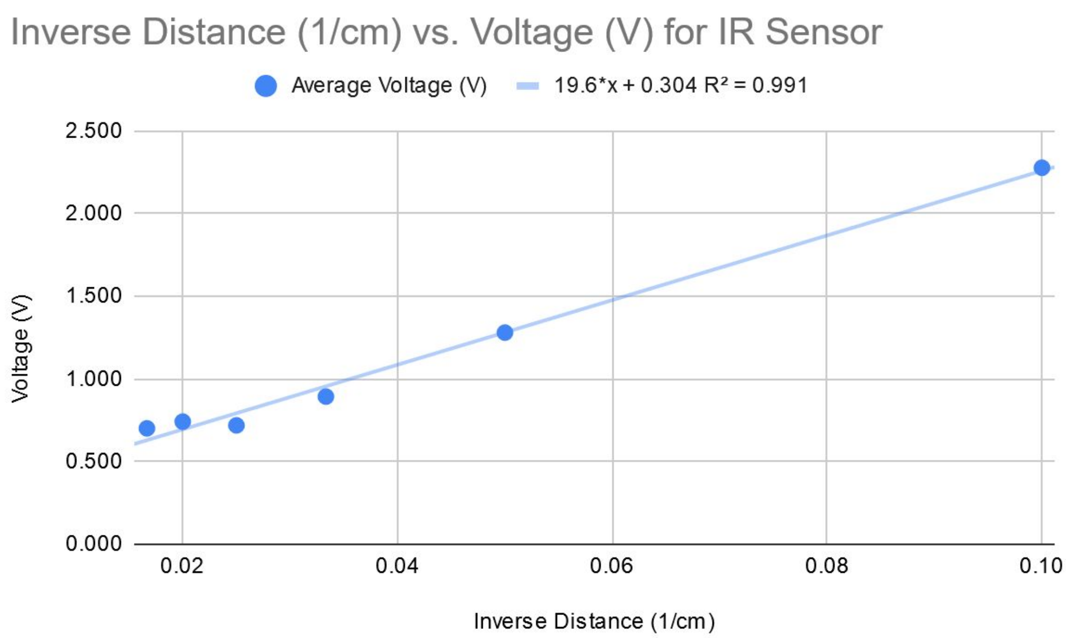

Figure 2.2: [Brian] Infrared Distance Sensor Voltage over Inverse Distance

Figure 2.3:

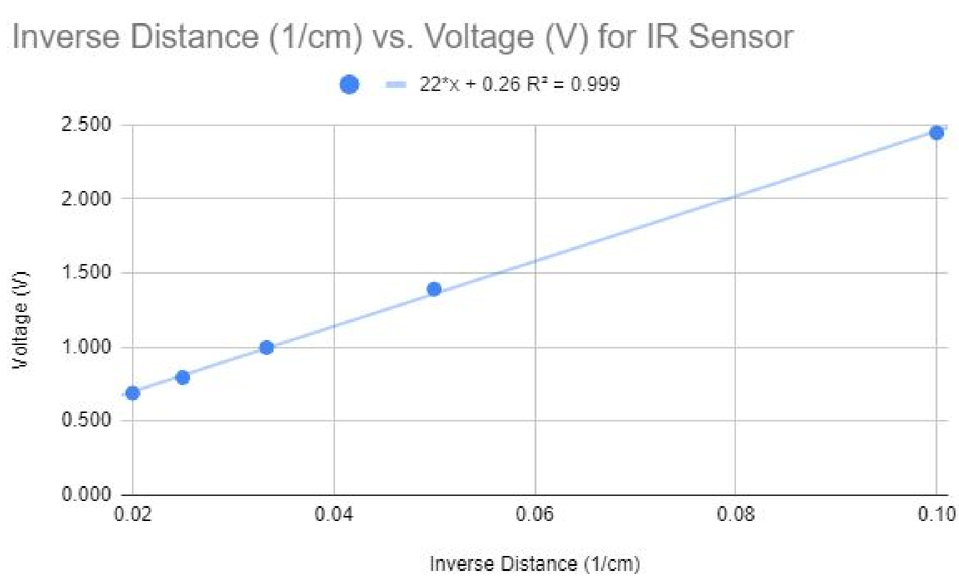

Figure 2.3: [Nick] Infrared Distance Sensor Voltage over Inverse Distance

b. Do the sensor responses have a reasonably linear form?
   i. The sensor responses do have a reasonably linear form when plotted against the inverse distance. The error between Best Fit and Average Voltage is at least an order of magnitude smaller than the Average (or Best Fit equation). Another indication of linearity can be seen in the correlation coefficient (r^2) of the linear regression, and a value closer to 1 indicates a linear form. As seen in Figure 2.2, the r^2 value is 0.991, which supports a strong linear relationship between voltage and inverse-distance.

6. IR distance reading averages
   a. Tables
      i. Matthew

Distance	Average Voltage (V)	Standard Deviation (V)	Best Fit $V = 20.248 * \frac{1}{d} + 0.1899$ (V)	Error (V)
10 cm	2.226	0.00503	2.2147	0.0113
20 cm	1.2075	0.00639	1.2023	0.0052
30 cm	0.8215	0.00490	0.86483	-0.0433
40 cm	0.65	0.00649	0.6961	-0.0461
50 cm	0.5915	0.02207	0.59486	-0.00336
60 cm	0.6035	0.01899	0.52737	0.07613

      ii. Brian

Distance	Average Voltage (V)	Standard Deviation (V)	Best Fit $V = 19.6 * \frac{1}{d} + 0.304$ (V)	Error (V)
10 cm	2.278	0.0161	2.264	0.014
20 cm	1.281	0.0139	1.284	-0.003
30 cm	0.894	0.0118	0.957	-0.064
40 cm	0.720	0.0115	0.794	-0.074
50 cm	0.742	0.0164	0.696	0.046
60 cm	0.702	0.0131	0.631	0.071

iii. Nick

Distance	Average Voltage (V)	Standard Deviation (V)	Best Fit $V = 22 * \frac{1}{d} + 0.26$ (V)	Error (V)
10 cm	2.446	0.0338	2.460	-0.014
20 cm	1.392	0.0447	1.360	0.032
30 cm	0.997	0.0478	0.993	0.004
40 cm	0.795	0.0459	0.810	-0.016
50 cm	0.689	0.0067	0.700	-0.011
60 cm	0.740	0.0363	0.627	0.113

7. Data comparisons between robots
   a. Errors
      i. The differences between each sensor can be seen in the errors across the three robots.The errors present in each robot for the IR sensor are much more similar than the ultrasonic sensor. This leads us to believe that the IR sensors are more consistent and precise than the ultrasonic sensor. If the conditions for an IR sensor are ideal, it would be better to utilize this sensor for measuring distances.

   b. Other
      i. Another thing to note is the standard deviation across the measurements -- Matt's sensor has a lower standard deviation than that of Brian and Nick's sensors, by a whole order of magnitude, which can be a testament to the consistency and precision of each individual sensor.

8. Advantages and disadvantages of IR proximity sensor
   a. Advantages
      i. IR sensors can detect "unseeable" objects such as gases. These sorts of readings can be helpful when monitoring systems that can't be visually observed or measured by means of standard tools. (i.e. distance can be measured with a device such as a tape measure)
      ii. IR sensors can both emit and detect radiation which gives the sensor several functionalities and use cases. This makes it possible to both measure the heat emitted by an object and its distance.
      iii. Because it relies on infrared light, the sensor is not disturbed by varying light sources unlike a reflectance sensor. This makes sensing in different environments such as smoky buildings and dark/bright spaces possible

b. Disadvantages
    i. Due to the inherent nature of the sensor utilizing infrared, the sensor is unable to create images in color like a camera. It can however be specified to show different heat levels for visualization.
    ii. If objects in close proximity are of the same heat signature, the IR sensor will have difficulty detecting the difference between the objects.
    iii. Infrared waves that are of high power can be harmful to eyes. This can make using this type of high powered sensor difficult in a setting with a large human or animal population
    iv. IR based sensors also suffer when trying to detect low reflectance surfaces as some do not reflect enough light for the sensor to function properly.