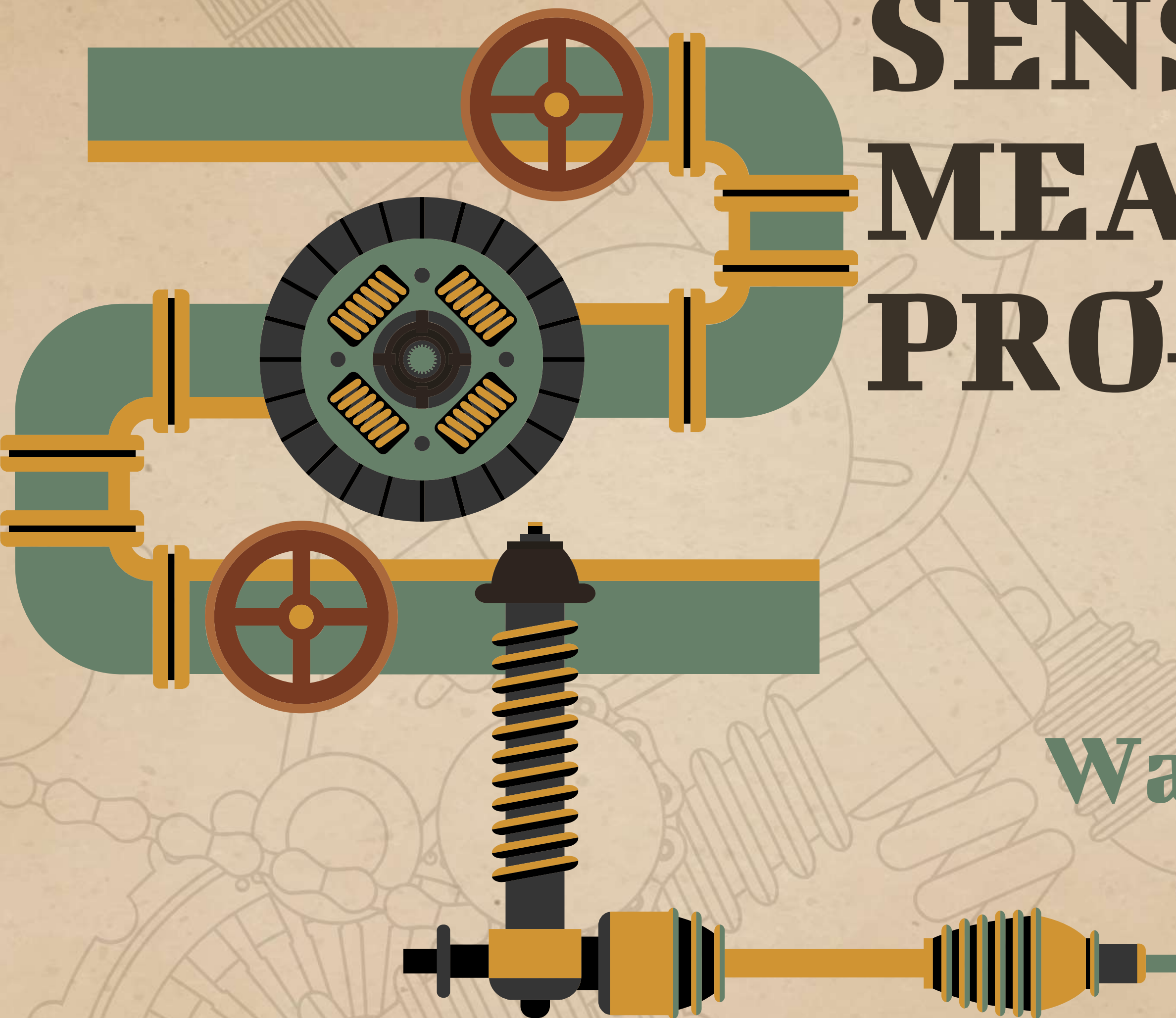

SENSOR(s) MEASUREMENT PROJECT

MPU6050 Module
DHT-11
Ultrasonic
Water Level Detection

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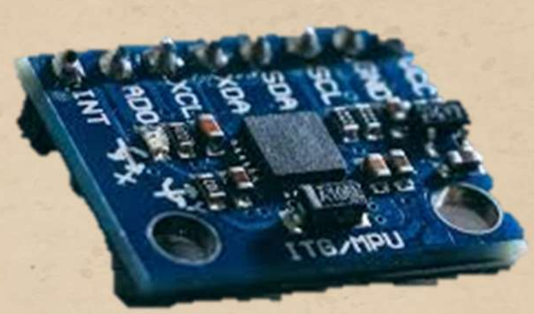
Cheng Chen and
Iretomiwa Idowu



MPU6050 Module

The MPU6050 is a multi-axis accelerometer and gyroscope that measures linear acceleration and angular acceleration respectively.

Working Principle

The accelerometer measures linear acceleration by using tiny systems to see how close to plates are to each other.

The gyroscope measures angular acceleration and it does this with a continuously oscillating mass and the known physics of the Coriolis effect.

Important Characteristics

- Range
- Sensitivity
- Resolution
- Linearity
- Repeatability
- Accuracy
- Precision

Specs Table/ Datasheet

Accelerometer ODR range	8kHz to 1.25Hz
Accelerometer Range	±2g, ±4g, ±8g, ±16g
Accelerometer sensitivity	at ±2g: 16384 LSB/g at ±4g: 8192 LSB/g at ±8g: 4096 LSB/g at ±16g: 2048LSB/g
Gyroscope ODR range	8kHz to 1.25Hz
Gyroscope range	± 250, ± 500, ± 1000, ± 2000 dps
Gyroscope sensitivity	at ±250dps: 131 LSB/dps at ±500dps: 65.5 LSB/dps at ±1000dps: 32.8 LSB/dps at ±2000dps: 16.4 LSB/dps

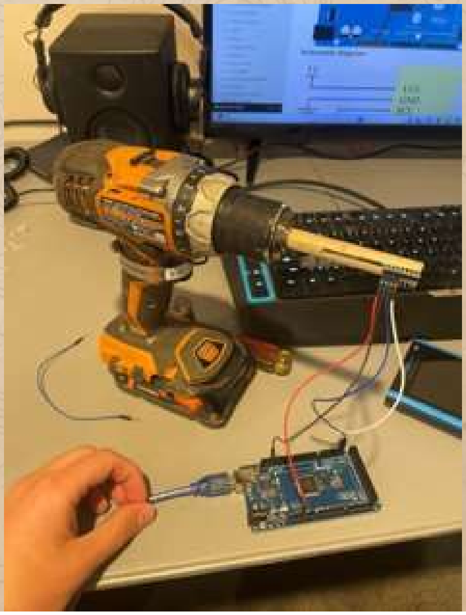
Measurement Process

Accelerometer

- **Ground Truth - Utilized centripetal acceleration formula to find ground truth based on angular velocity**
- $a_c = \frac{v^2}{r}$ *and* $v = \omega r$ *which turns into* $a_c = \omega^2 r$
- **Measures in g's**

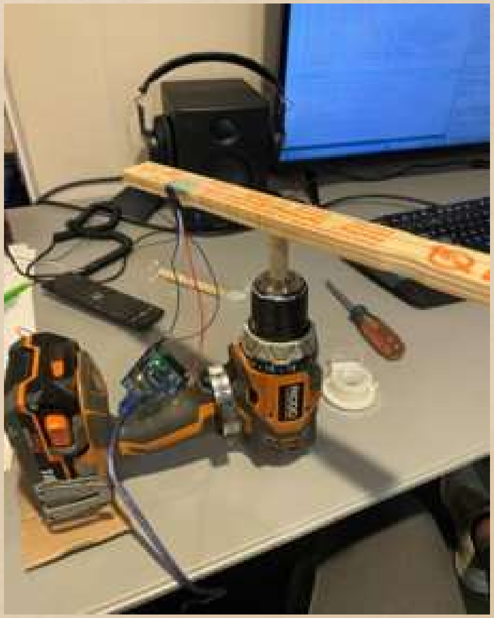
Gyroscope

- **Ground Truth- Determined angular velocity using supplied encoder**
- **Assumed higher accuracy from encoder dur to counting instead of measuring**
- **Measured in degrees per second**

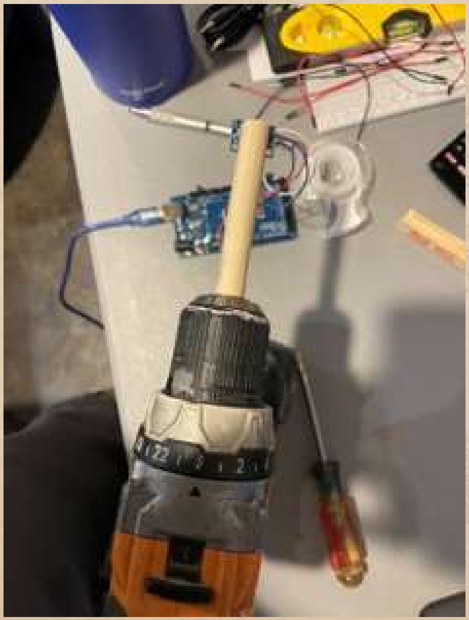


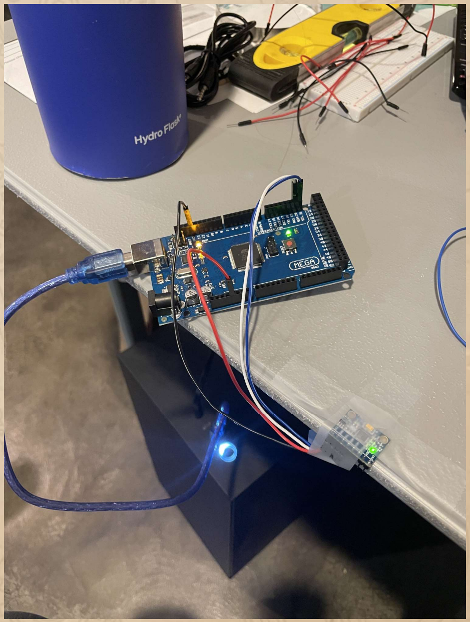
More pictures of the testing Setup

Accelerometer Testing Setup



Gyroscope Testing Setup



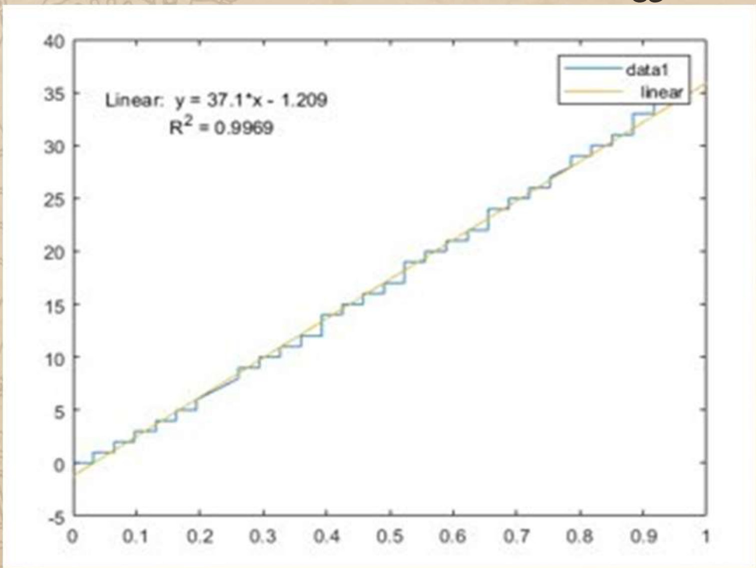


Ground Truth

Ground Truth Value

The goal was to obtain angular velocity of a drill at different points

- Issues with encoder being unable to keep up
- Issues with recreating speeds



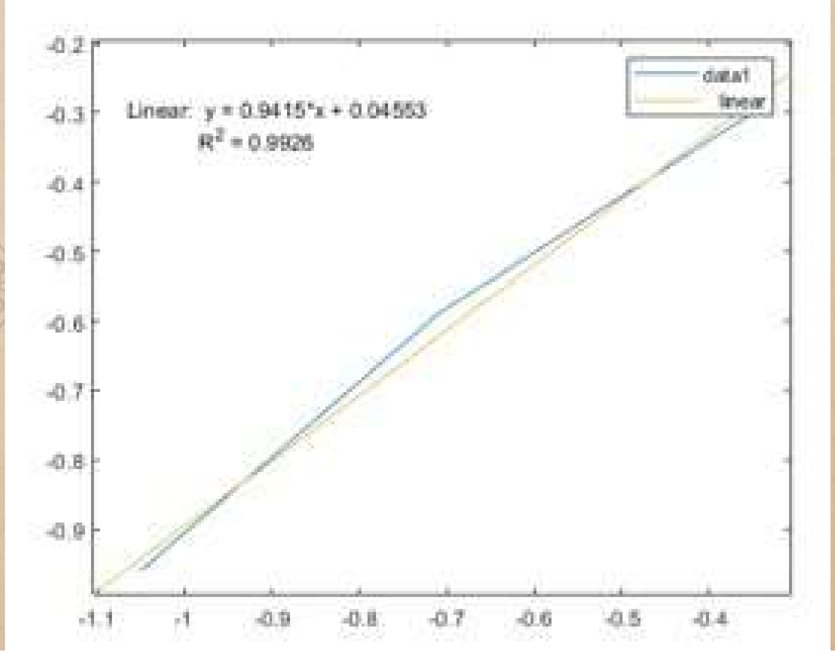
Ground Truth Result

Angular Velocity estimation of ~37.1 counts/second

- 20 counts per rotation according to data sheet
  - $\omega = \sim 11.65 rad/s = 667.8 dps$

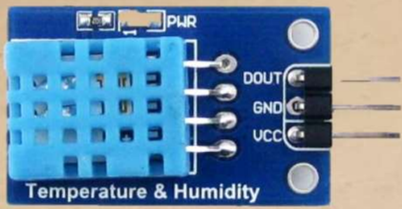
Sensor Characteristics Accelerometer Results

- Repeatability
  - Measurements along Y axis
    - 1 inch: [-0.28g, -0.29g, -0.33g] with average of -0.30g, expected -0.35g
    - 2 inch: [-0.61g, -0.54g, -0.63] with average of -0.59g, expected -0.71g
    - 3 inch: [-0.84g, -0.92g, -1.13g] with an average of -0.96g, expected -1.05g
- Range
  - Unable to test due to wires
- Sensitivity
  - Expected
- Resolution
  - Needed to accurately control



Summary of findings and Improvements

- Use 12V motor and something like PWM to control angular velocity
  - Verify with better encoder
- Mount motor at exactly horizontal or vertical
- Power Arduino without computer (battery)
- Utilize onboard storage for results when set up is moving



DHT-11 Module

The DHT-11 is a temperature and humidity sensor. It features a resistive-type humidity measurement component, a NTC temperature measurement component and an 8-bit microcontroller. Its primary purpose is to measure temperature and humidity.

Working Principle

The DHT11 sensor consists of a capacitive humidity sensing element and a thermistor for sensing temperature.

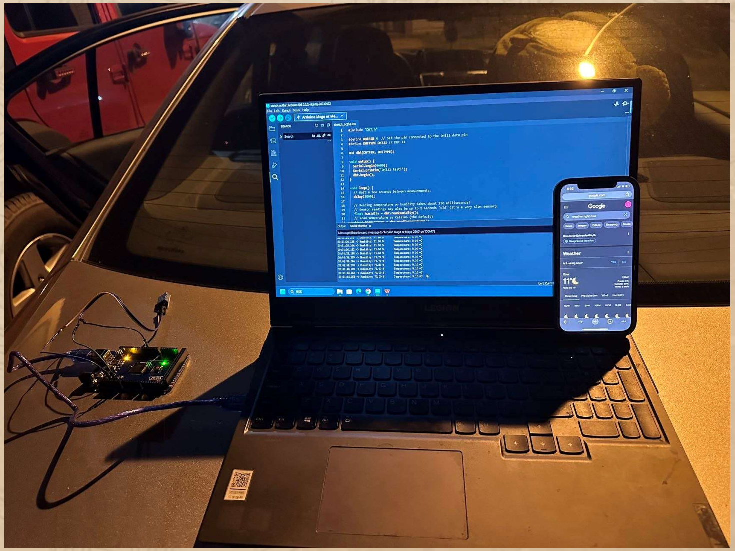
Important Characteristics and Specs Table

Parameters	Conditions	Minimum	Typical	Maximum
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			±1%RH	
Accuracy	25℃		±4%RH	
	0-50℃			±5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0℃	30%RH		90%RH
	25℃	20%RH		90%RH
	50℃	20%RH		80%RH
Response Time (Seconds)	1/e(63%)25℃, 1m/s Air	6 S	10 S	15 S
Hysteresis			±1%RH	
Long-Term Stability	Typical		±1%RH/year	
Temperature				
Resolution		1℃	1℃	1℃
		8 Bit	8 Bit	8 Bit
Repeatability			±1℃	
Accuracy		±1℃		±2℃
Measurement Range		0℃		50℃
Response Time (Seconds)	1/e(63%)	6 S		30 S

Measurement Process and Ground Truth

As for how to measure, the method I choose is to use the car air conditioning, and because the car has a more accurate temperature sensor that could serve as the ground truth and thus can be compared with the temperature measured by the DHT-11 sensor. The characteristics I choose to measure are drift, static error and linearity. Therefore, there is no need to use a very low temperature, and the car air conditioning is fully competent for this job In the car, we can turn on the automatic mode of the air conditioner, and when the specified temperature is reached, the air conditioner will stop, and we can use the sensor to measure

Testing Setup



Rundown of characteristics measurement process , Data collected , Findings and Analysis

Drift

For drift, we put the sensor outside to measure the temperature of the day and check the temperature of the day according to the phone. And keep the sensor running for one minute ,we can get under data.

the temperature is still 11*C

19:58:54.085 -> Humidity: 66.50 Temperature: 10.20 *C

19:58:56.110 -> Humidity: 66.60 %   Temperature: 10.20 *C

19:58:58.156 -> Humidity: 66.70 %   Temperature: 10.20 *C

19:59:00.187 -> Humidity: 66.80 %   Temperature: 10.20 *C

19:59:02.215 -> Humidity: 66.80 %   Temperature: 10.20 *C

19:59:04.229 -> Humidity: 66.80 %   Temperature: 10.20 *C

19:59:06.269 -> Humidity: 66.90 %   Temperature: 10.10 *C

19:59:08.287 -> Humidity: 67.00 %   Temperature: 10.10 *C

19:59:30.593 -> Humidity: 67.80 %   Temperature: 9.90 *C

we can see that when we keep the input to be 11, but the measure temperature is still changing.

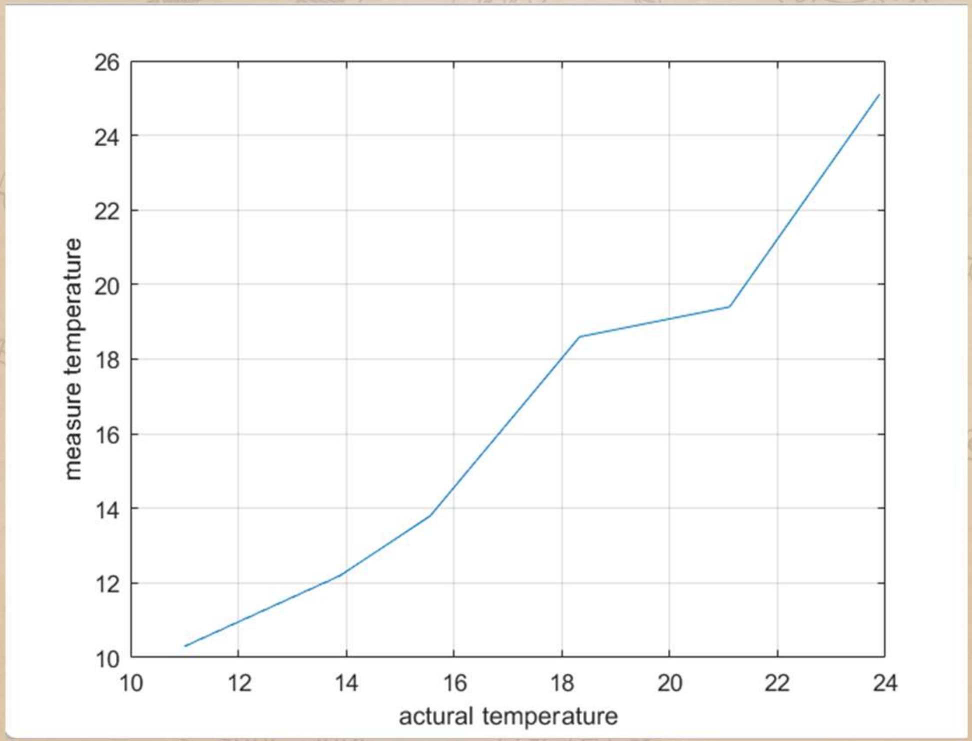
Static Error

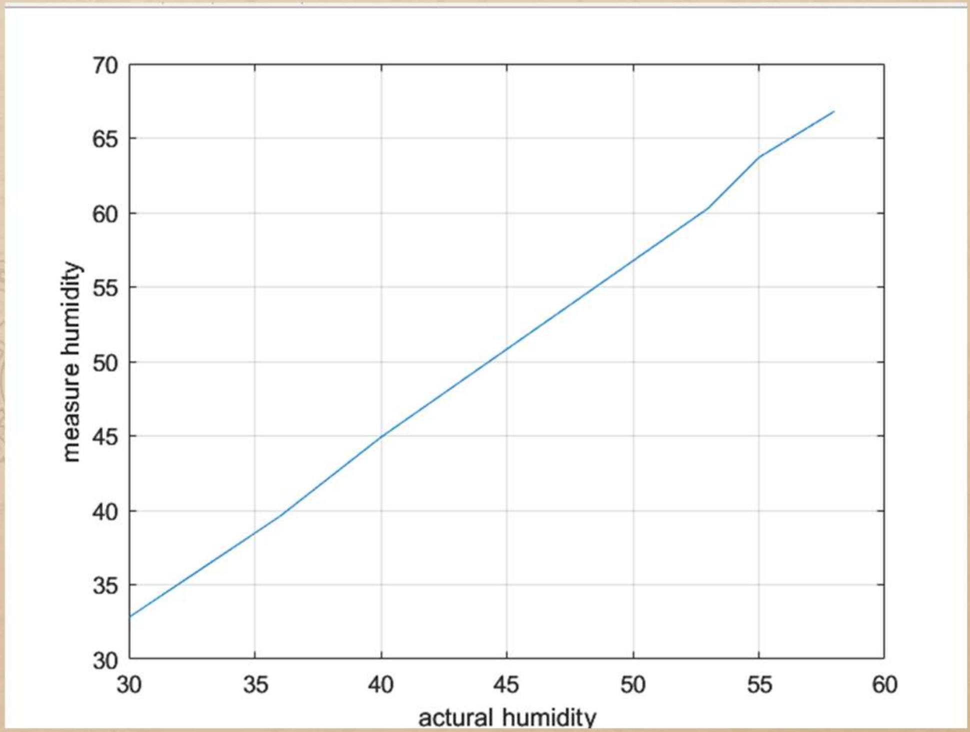
Keep the temperature inside the car at () °C, then use DHT-11 to get the output, and compare with the vehicle thermometer reading, repeat for 3 groups

actural temperature	measure temperature	%error	actural humidity	measure humidity	%error
11	10.3	6.36	58	66.8	13.17
13.89	12.2	12.16	55	63.7	15.81
15.56	13.8	11.31	53	60.3	13.77
18.33	18.6	1.47	40	44.9	12.25
21.11	19.4	8.1	36	39.6	10
23.89	25.1	5.06	30	32.8	9.33

Linearity

For linearity, we adjust the temperature in the car to a certain value, then put the sensor in the car, and read a stable output after a period of time. Changing the temperature inside the car was repeated six times, and we chose to use MATLAB to draw the graph to observe whether it was linear





Summary of Findings

- Temperature adds up everywhere which is why the first time we tried measuring , our readings were off by a considerable amount which we did not know at that time was out body temperature

- It took about 10 mins for the sensor to go from the previous temperature to the new temperature(this is where most of the lack of the sensor was coming from

- The longer the sensor stayed at a temperature the more the drift!

Water level Detection sensor

The Water Level Detection Sensor very self-descriptive as it does what it says it does: detect water level. It features ten copper wires in which 5 are sense traces and the remaining five are power traces

Working Principle

The sensor produces an output voltage proportional to the resistance; by measuring this voltage, the water level can thus be determined, measured and thus displayed!

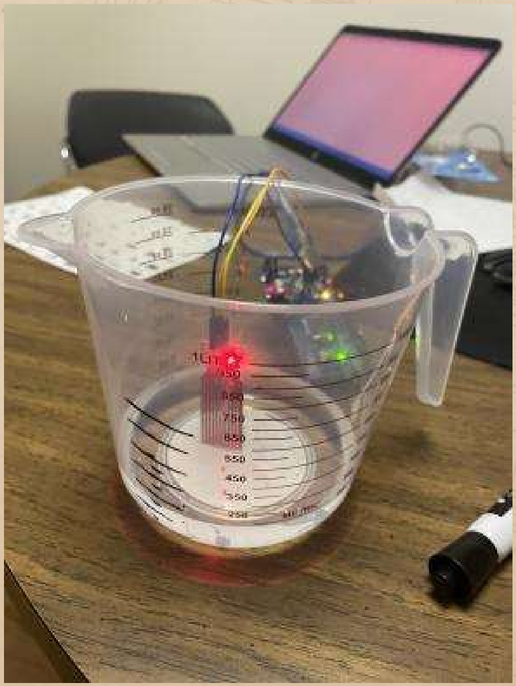
Important Characteristics and Specs Table

Sensor Type	Analog
Detection Area	40mm * 16mm
Operating temperature	10℃-30℃ Humidity: 10% - 90% non-condensing

Measurement Process and Ground Truth

The ground truth was not only easily accessible but also easy to measure. We used a tape rule to measure and mark the ground truths of the length on transparent cup, we then went on to fill water to those levels and used the sensor to once again confirm the ground truth.

Testing Setup



Static Characteristics Measurement Process

Range

To measure the range, we submerged the sensor in water and gradually increase the depth until it no longer detected water. We then compared this to the range specified by the data sheet

Sensitivity/Linearity

To measure sensitivity, we slowly increased the water level while observing the sensor's output. We did this till we obtained multiple readings, plotted it and then extracted the data we needed to quantify these characteristics

Resolution

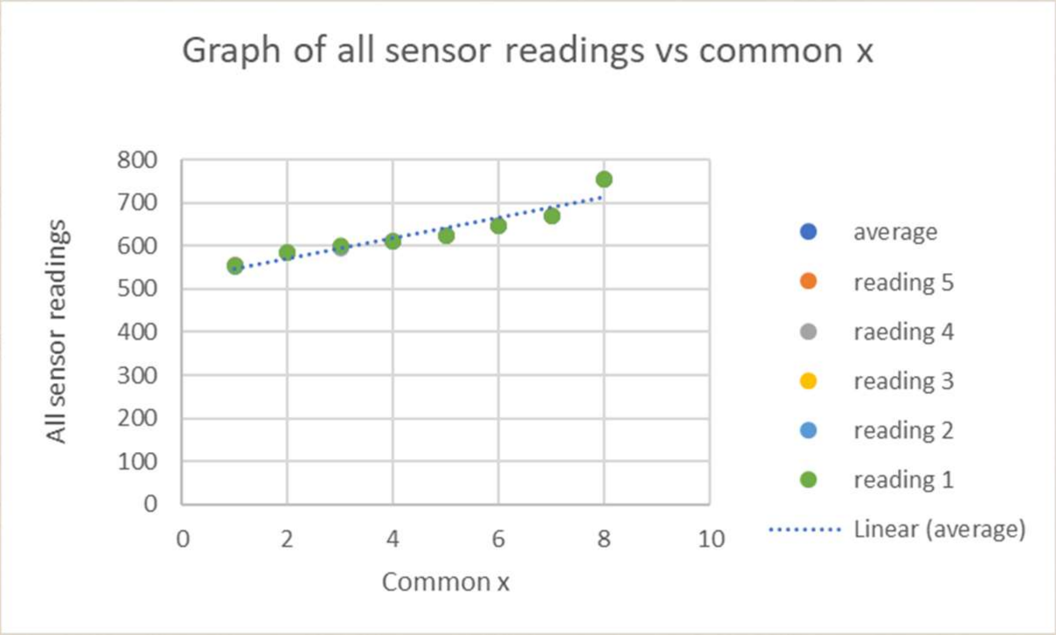
As mentioned in the proposal, we tried to measure resolution, and to do this we tried making small incremental changes in water level and observing the corresponding changes in the sensor's output. We found this really hard as the uncertainty was once again to high to ignore

Precision, Accuracy and Repeatability

To measure this, we obtained multiple readings at same water level (with the water level already premeasured) and then used Excel to calculate the standard deviation of the readings from each other and the ground truth.

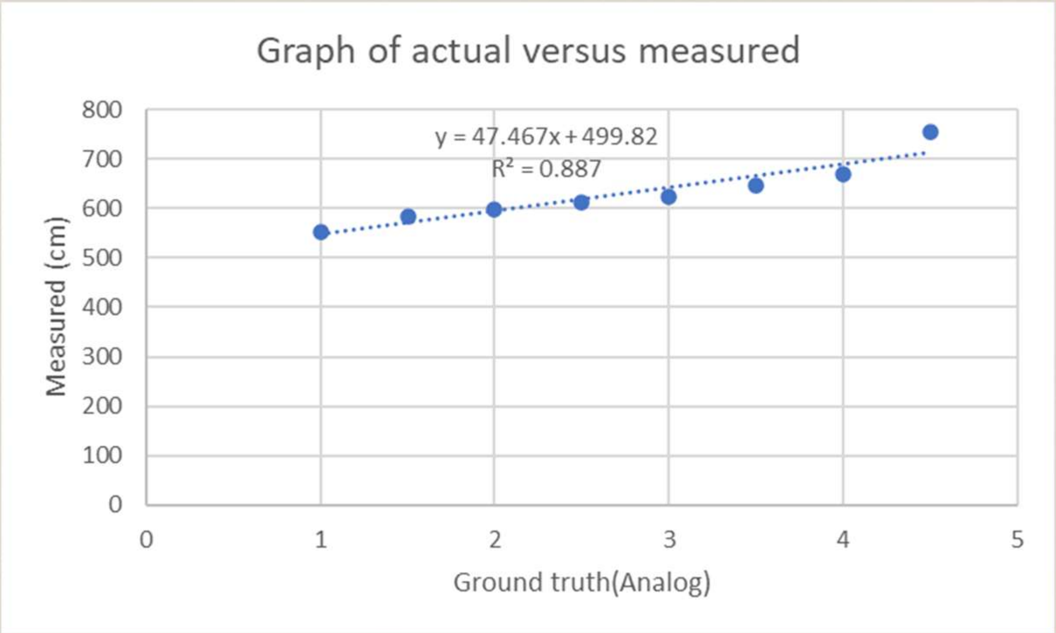
Data collected, Findings and Analysis

- Precision –Looking at the graph, all points overlap the ground truth
- Repeatability – Again values overlap each other
- Drift – 5 readings spread out within 1 mins → ± 2



Data collected, Findings and Analysis

- Linearity R^2 = 0887. This shows that the graph is not as linear as we would want it to be but this is to be expected due to the fluctuations
- Range –Accurate within the manufacture spec (1.6 - 4cm)
- Resolution: Cannot be quantified due to the error we observed during testing
- Sensitivity: Slope =47.467



Comparison and Summary of Findings

- From the data to the side, we can conclude a lot of things but the most important things we need to focus is that the data matches the data sheet especially the range
- Water waves made the readings fluctuate before stabilizing which took about 20seconds decreasing the linearity of the sensor

	Sensor Analog Readings								
True Value(cm	1	2	3	4	5	Average	Std	Deviation	Error
1	554	553	553	554	554	553.6	0.547723	1	55260
1.5	585	584	584	584	585	584.4	0.547723	1	38860
2	600	597	597	596	597	597.4	1.516575	4	29770
2.5	612	612	610	610	612	611.2	1.095445	2	24348
3	625	625	625	625	625	625	0	0	20733.33
3.5	648	648	648	648	647	647.8	0.447214	1	18408.57
4	669	669	669	669	669	669	0	0	16625
4.5	755	754	754	755	754	754.4	0.547723	1	16664.44

Ultrasonic Module

The HS-SR04 is a proximity sensor. It features two ultrasonic transducers. One is transmitter which outputs ultrasonic sound pulses and the other is receiver which listens for reflected waves. Its primary purpose is to measure distance

Working Principle

It uses the echo time method to detect the time of ultrasonic round trip to the measured distance.

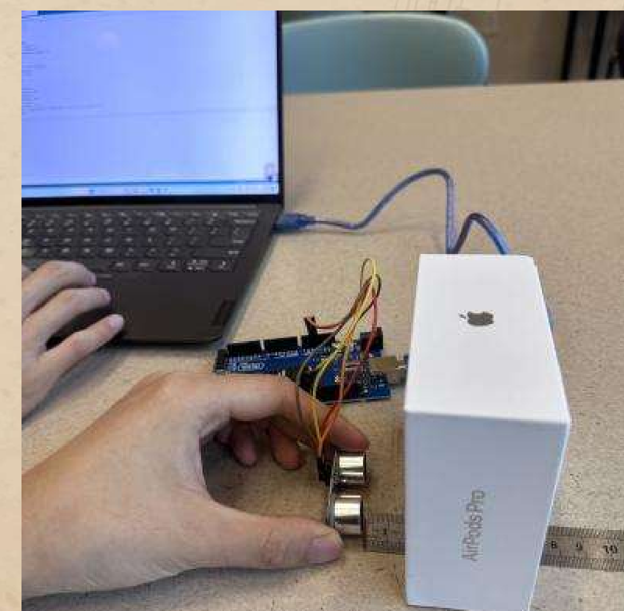
Important Characteristics and Specs Table

Range	2cm – 400cm (Practically 80cm)
Accuracy	± 3mm
Resolution	0.3cm
Sensitivity	-65dB min

Measurement Process and Ground Truth

The ground truth was not only easily accessible but also easy to measure. We used a ruler and a tape rule at two different instances to measure the ground truth and then set up the sensor and an obstacle in a way that we could increase and decrease distance as needed. See below

Testing Setup



Static Characteristics measurement process

Range

First, we put the sensor and the object together, at which point the measurement distance is too small to be beyond the sensor's measurable range, so the readings are approximately infinite. Then we slowly move the object away until a recognizable reading appears, which we use as the minimum value of the sensor. Then we gradually move the object away from the sensor in units of 10cm, and when the reading shows infinity again, the description is beyond the maximum range, and then we gradually move the object closer to the sensor in 1cm units to find the critical point where the reading can be identified and the reading is approximately infinite. This distance was then considered the maximum value that the sensor can measure.

Sensitivity

The sensor in different distance several times, The measured data was then averaged and compared with the actual distance. Then the measured distance and the actual distance are used as horizontal and vertical coordinates to plot their functions.

Quick run though of measurement process

Resolution

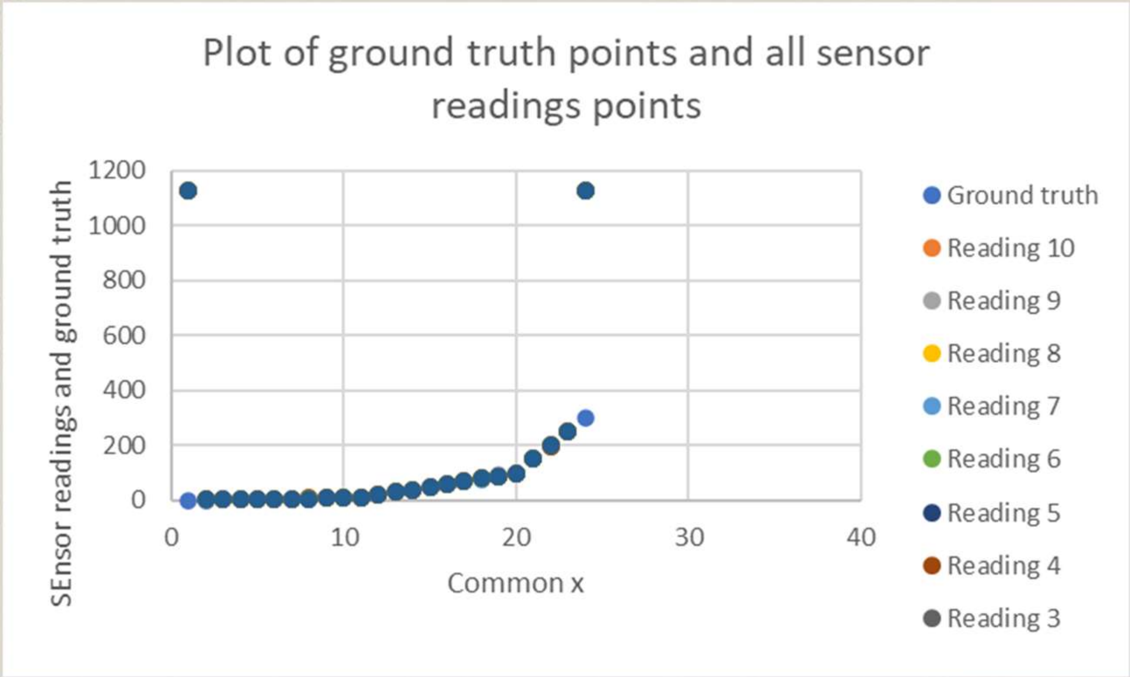
We tried this by setting the sensor at a premeasured distance and with the ruler in between the sensor and the object, we tried adjusting the distance in increments of 0.1cm till we start getting a discernable output from the sensor. But the data was not reliable due to too much uncertainty which you can observe in the deviation

Accuracy, Precision Reliability

For this we just took multiple readings of different distances, plotted the values against each other and extracted the data we needed to qualify and quantify these characteristics as can be seen in the next slide .

Data collected, Findings and Analysis

- Accuracy/Precision – Looking at the graph, all points neglecting the outliers overlap the ground truth
- Repeatability – Again values overlap each other
- Drift – 10 readings spread out within 2 mins $\rightarrow \pm 0.1$



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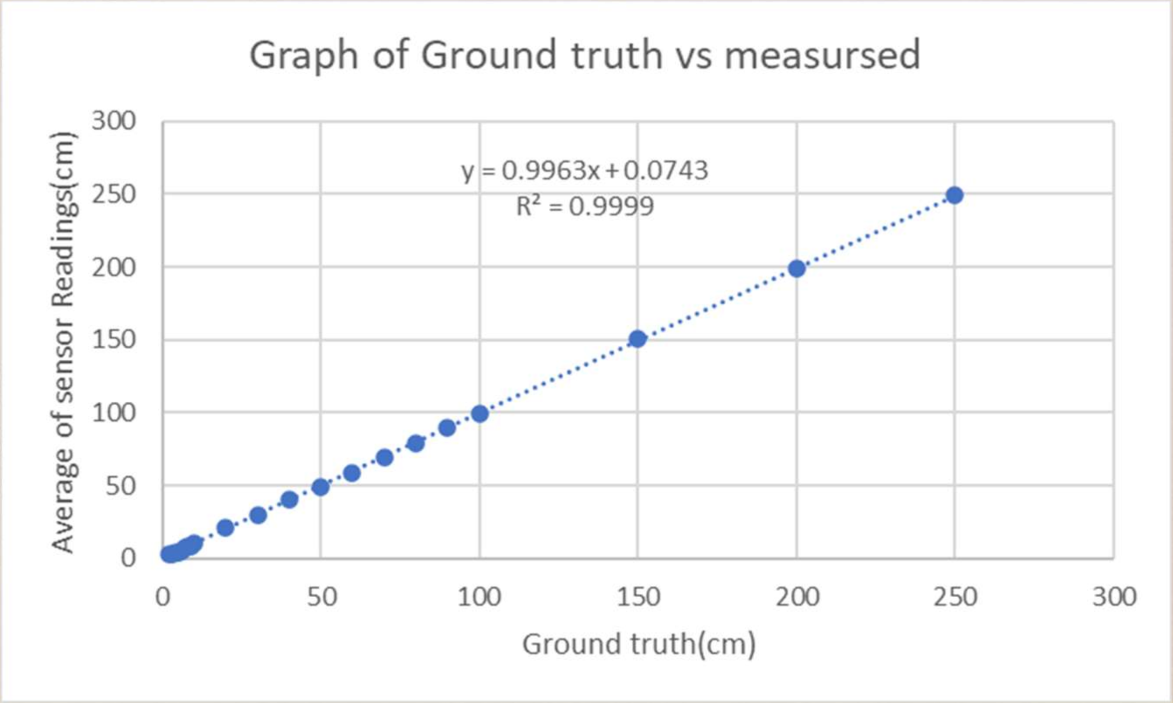
Data collected, Findings and Analysis

- Linearity R^2 = 0.9999, Also the equation of the graph is linear
- Range –Accurate within the manufacture spec (2 – 250cm)
- Resolution: Cannot be quantified due to the error we observed during testing
- Sensitivity: Slope = 0.9963



Comparison and Summary of Findings

- From the data to the side, we can conclude a lot of things but the most important things we need to focus is that the data matches the data sheet at the beginning of this section

	Sensor Readings													
Ground Truth(cm	1	2	3	4	5	6	7	8	9	10	Average	Std	Deviation	% Error
0	1126.03	1126.07	1126.12	1126.19	1126.36	1126.91	1126.88	1126.17	1126.17	1126.03	1126.293	0.33143	0.88	#DIV/0!
1	4.09	4.09	3.98	3.98	3.98	4.03	4.09	4.09	4.09	4.09	4.051	0.052377	0.11	305.1
2	2.88	2.76	2.88	2.86	2.86	2.88	2.88	2.86	2.78	2.86	2.85	0.043461	0.12	42.5
3	3.17	3.07	3.12	3.07	3.17	3.17	3.17	3.17	3.17	3.17	3.145	0.042492	0.1	4.833333
4	4.09	3.98	4.09	4.09	3.98	3.98	4.09	4.09	4.09	3.98	4.046	0.056804	0.11	1.15
5	4.59	4.69	4.71	4.69	4.59	4.69	4.71	4.69	4.69	4.59	4.664	0.051683	0.12	-6.72
6	5.6	5.6	5.6	5.6	5.5	5.62	5.5	5.5	5.62	5.5	5.564	0.055618	0.12	-7.26667
7	7.33	7.45	7.34	7.44	7.33	7.33	7.45	7.33	7.43	7.36	7.379	0.055668	0.12	5.414286
8	8.36	8.34	8.24	8.24	8.24	8.24	8.36	8.24	8.36	8.24	8.286	0.059666	0.12	3.575
9	8.93	9.02	8.91	9.03	8.93	9.02	8.91	9.02	8.91	9.02	8.97	0.055377	0.12	-0.33333
10	10.24	10.24	10.34	10.34	10.34	10.22	10.34	10.33	10.33	10.33	10.305	0.049944	0.12	3.05
20	20.86	20.86	20.86	20.84	20.84	20.84	20.74	20.74	20.74	20.84	20.816	0.053166	0.12	4.08
30	30.28	30.28	30.28	30.28	30.38	30.38	30.29	30.28	30.28	30.28	30.301	0.041753	0.1	1.003333
40	40.21	40.21	40.21	40.21	40.22	40.12	40.1	40.12	40.1	40.21	40.171	0.053009	0.12	0.4275
50	49.24	49.24	49.24	49.24	49.24	49.26	49.26	49.26	49.34	49.36	49.268	0.044422	0.12	-1.464
60	59.19	59.29	59.07	59.29	59.19	59.29	59.71	59.28	59.29	59.07	59.267	0.178889	0.64	-1.22167
70	69.12	69.12	69.12	69.12	69.21	69.22	69.12	69.22	69.12	69.21	69.158	0.049171	0.1	-1.20286
80	79.05	79.36	79.06	79.05	79.35	79.45	78.53	79.36	78.97	78.93	79.111	0.278147	0.92	-1.11125
90	89.38	89.36	89.36	89.4	89.29	89.4	89.36	89.38	89.36	89.48	89.377	0.047621	0.19	-0.69222
100	99.31	99.43	99.41	99.33	99.41	99.33	99.31	99.47	99.33	99.41	99.374	0.057966	0.16	-0.626
150	150.34	150.28	150.69	150.38	150.36	150.36	150.81	150.38	150.78	150.38	150.476	0.200344	0.53	0.317333
200	199.1	199.12	199.1	198.69	198.6	199.12	199.14	199.12	198.74	199.05	198.978	0.211912	0.54	-0.511
250	249.47	249.64	249.78	249.48	250.29	249.34	249.4	249.78	249.31	249.69	249.618	0.292567	0.98	-0.1528
300	1124.55	1124.65	1126.45	1126.45	1126.55	1126.56	1124.45	1124.45	1124.67	1124.89	1125.367	0.985743	2.11	275.1223
												0.139551	0.36125	27.18571
												0.09427	0.265238	2.14519

Conclusion

- The sensors were not up to industry standard but they do what they are supposed to do and this here we come in – to make up for that gap with our time and effort .

- The sensors are not that crappy and we lost time focusing on that but at the end of the day we realized what we had to do!

Thank You

Q/A