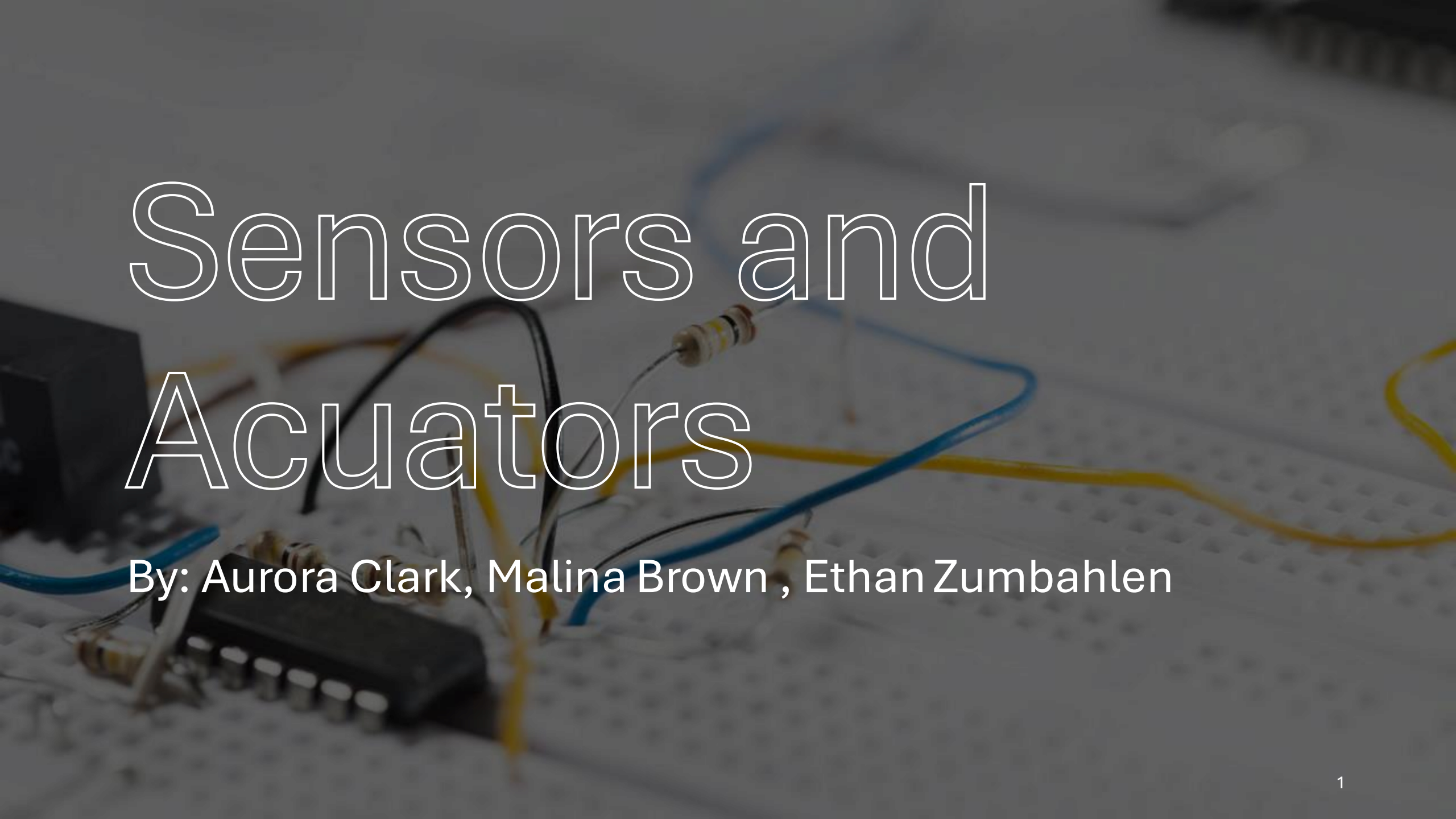


Sensors and Acuators

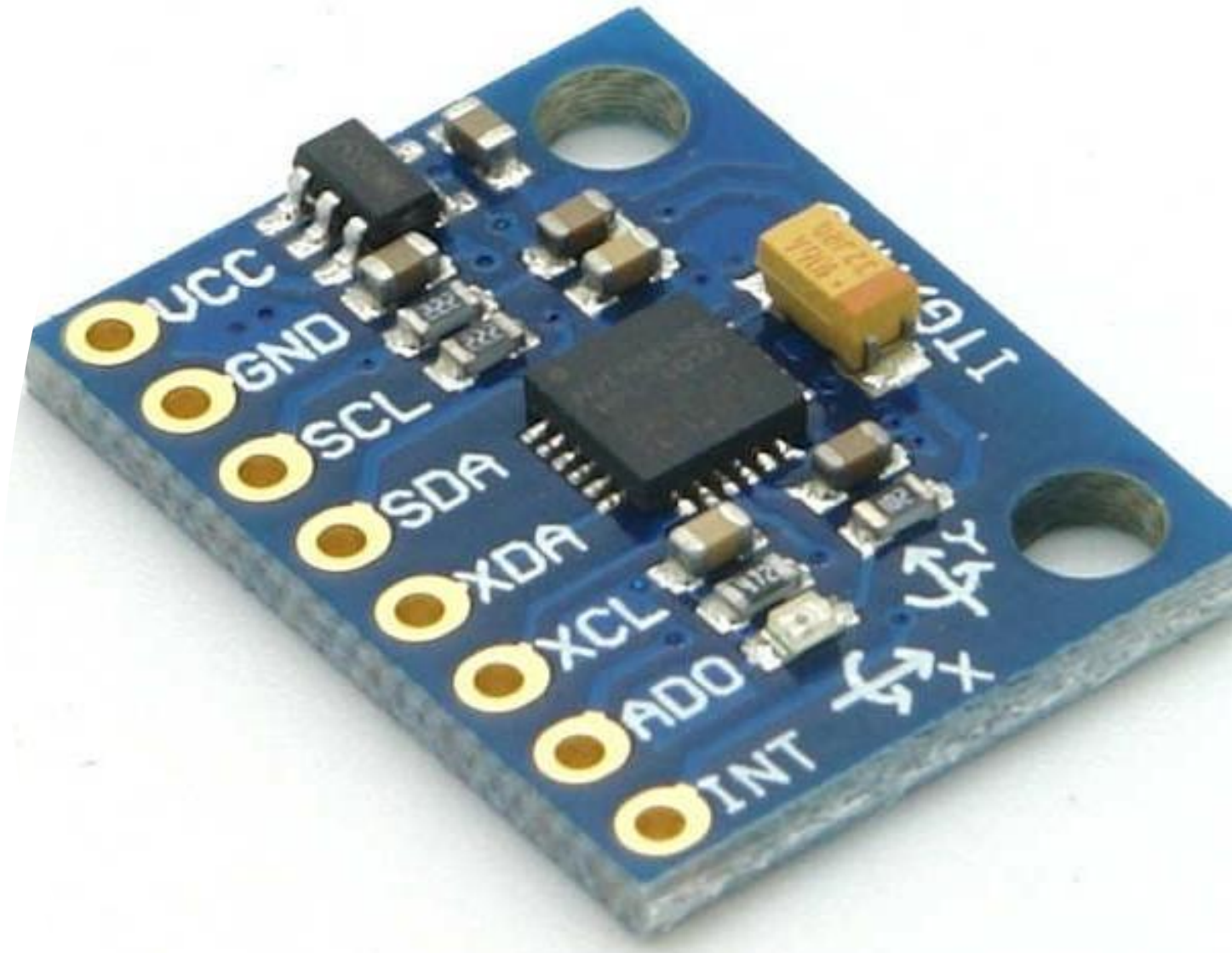
By: Aurora Clark, Malina Brown , Ethan Zumbahlen

MPU 6050

An MPU6050 has a 3-axis accelerometer and a 3-axis gyroscope that measures linear motion and angular motion, respectively.

The accelerometer uses the Piezo electric effect to measure inclination and magnitude.

The gyroscope, on the other hand, uses the Coriolis effect to measure motion around the x, y, and z axes. (Roll, Pitch, Yaw)



6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		mg	1
	Z axis		±80		mg	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		mg	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		µg/ √Hz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		260	Hz	
OUTPUT DATA RATE						
	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		mg/LSB	

6 Electrical Characteristics

6.1 Gyroscope Specifications

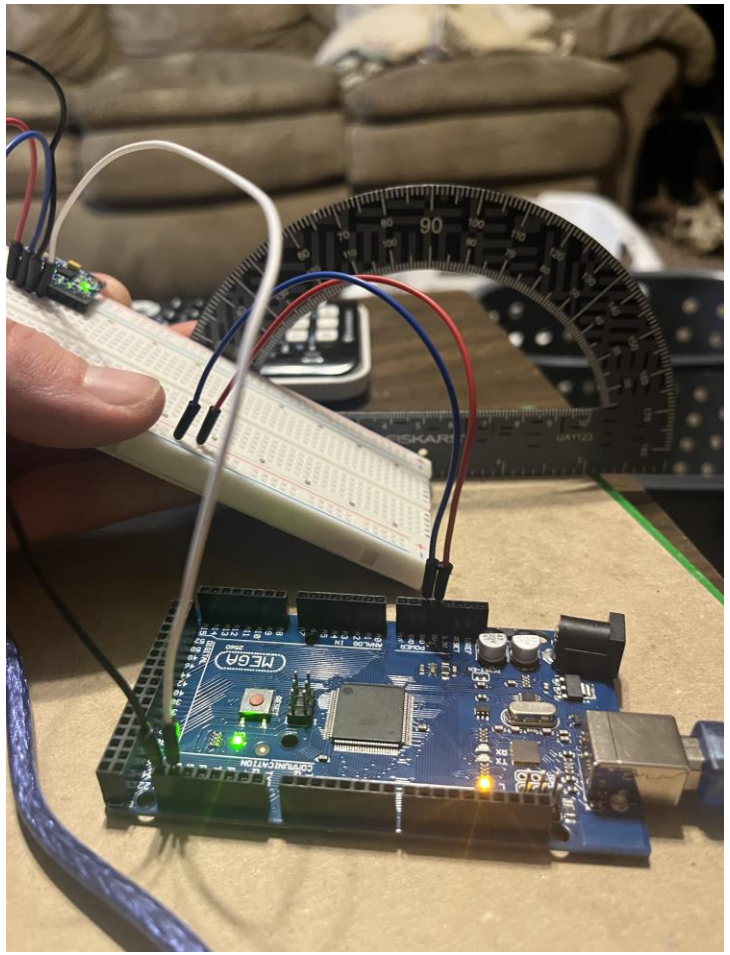
VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

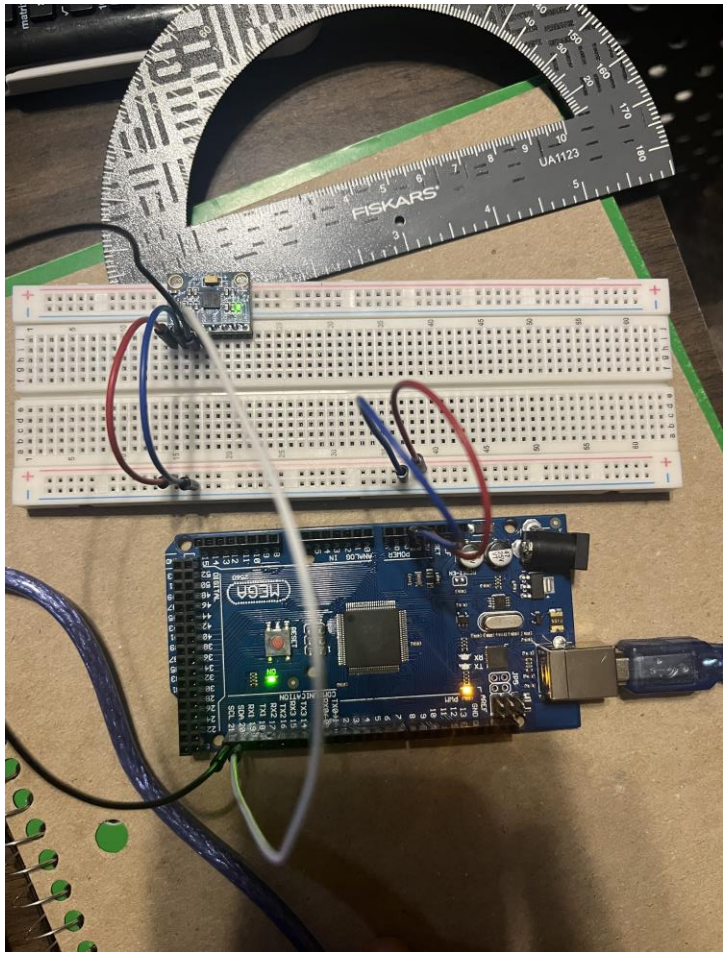
PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
GYROSCOPE SENSITIVITY						
Full-Scale Range	FS_SEL=0		±250		°/s	
	FS_SEL=1		±500		°/s	
	FS_SEL=2		±1000		°/s	
	FS_SEL=3		±2000		°/s	
Gyroscope ADC Word Length			16		bits	
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(°/s)	
	FS_SEL=1		65.5		LSB/(°/s)	
	FS_SEL=2		32.8		LSB/(°/s)	
	FS_SEL=3		16.4		LSB/(°/s)	
Sensitivity Scale Factor Tolerance	25°C	-3		+3	%	
Sensitivity Scale Factor Variation Over Temperature			±2		%	
Nonlinearity	Best fit straight line; 25°C		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	25°C		±20		°/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		°/s	
Power-Supply Sensitivity (1-10Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		°/s	
Power-Supply Sensitivity (10 - 250Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		°/s	
Power-Supply Sensitivity (250Hz - 100kHz)	Sine wave, 100mVpp; VDD=2.5V		4		°/s	
Linear Acceleration Sensitivity	Static		0.1		°/s/*g*	
SELF-TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	1
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (100Hz)		0.05		°/s-rms	
Low-frequency RMS noise	Bandwidth 1Hz to10Hz		0.033		°/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		°/s/ √ Hz	
GYROSCOPE MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	
Y-Axis		27	30	33	kHz	
Z-Axis		24	27	30	kHz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		256	Hz	
OUTPUT DATA RATE						
	Programmable	4		8,000	Hz	
GYROSCOPE START-UP TIME	**DLPFCFG=0**					
ZRO Settling (from power-on)	to ±1°/s of Final		30		ms	

Important Characteristics

- Range
  - Range will be tested by measuring the highest and lowest values of the stimulus
- Sensitivity
- Linearity
  - Sensitivity and Linearity will be measured from the transfer function
- Accuracy
  - Will be comparing angles recorded by the sensor with a protractor
- Drift
  - This will be tested by recording the values of the sensor in a specific position and recording any deviation of those values for a period of time

Testing Process and Illustration

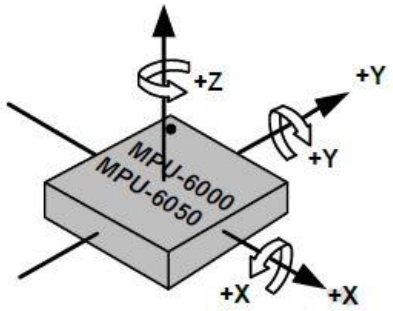




- Testing this sensor using a protractor and stopwatch
- In using the protractor, we can find the angle and using a ruler and a stopwatch speed can be derived from v = d/t
- Because the sensor starts from a complete stop shows its acceleration which can be found via $\Delta x = V_i t + 1/2at^2$

Testing Angles

```
Serial.print(" AcX = "); Serial.print(AcX / 65536 * ACCELE_RANGE+0.08); Serial.print("g ");
Serial.print(" | AcY = "); Serial.print(AcY / 65536 * ACCELE_RANGE); Serial.print("g ");
Serial.print(" | AcZ = "); Serial.print(AcZ / 65536 * ACCELE_RANGE-0.10); Serial.println("g ");
```



Testing accelerators			
Distance	X	Y	Z
0 in	-0.01 g	0.06 g	1.13 g
1 in/s	0.04 g	0.03 g	1.15 g
3 in/s	0.04 g	0.03 g	1.15 g
5 in/s	0.04 g	0.03 g	1.15 g

Testing the Gyros			
Degrees in 1 sec	Gx	Gy	Gz
0	0.05 d/s	-2.50 d/s	0.25 d/s
15	-15.47 d/s	11.97 d/s	19.94 d/s
30	-32.88 d/s	-30.56	-28.13
45	-42.99 d/s	-45.68 d/s	-45.33 d/s
60	-63.58 d/s	-56.68 d/s	-67.26 d/s
90	-116.54 d/s	-121.92 d/s	-108.30 d/s

Results

Comparing test results with the manufacture specs can verify that our results are withing range

Manufacture Specs / Gyro range

±250 d/s

±500 d/s

±1000 d/s

±2000 d/s

Test results / Gyro

- Min Val 0
- Max Val 90 d/s

Manufacture Specs / Accelerometer range

- ±2 g
- ±4 g
- ±8 g
- ±16 g

Test results / Accelerometer

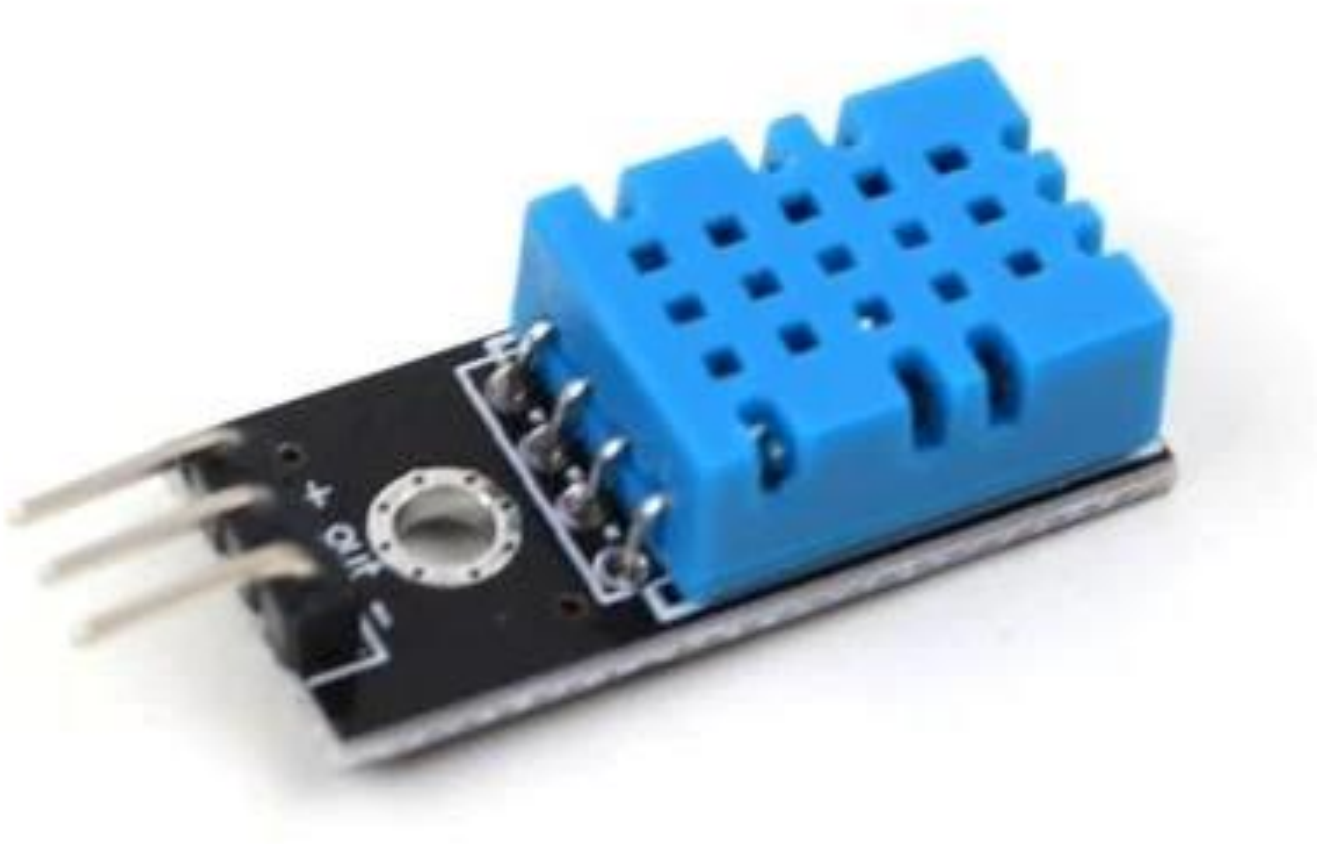
- Does not change when tested

DHT-11

The DHT-11 is a commonly used low-cost temperature and humidity sensor, it is used to measure the air and gives an output of the current temperature and humidity at a rate every 1-2 seconds (or whatever you specify in the delay).

It features a calibrated digital signal output. It has a resistive-type humidity measurement component, an NTC temperature measurement component, and an 8-bit microcontroller for serial outputs for temperature and humidity.

The dht11 library is need to use the Arduino code.



DHT11 Specifications

- Operating Voltage: 3.5V to 5.5V
- Operating current: 0.3mA (measuring) 60uA (standby)
- Output: Serial data
- Temperature Range: 0°C to 50°C
- Humidity Range: 20% to 90%
- Resolution: Temperature and Humidity both are 16-bit
- Accuracy: ±1°C and ±1%

Important Characteristics

- ❖Accuracy
- ❖Range
- ❖Resolution

<u>How the sensor was tested:</u>

- The accuracy was tested indoors and outdoors by comparing the measurements of the DHT-11 to an indoor/outdoor AcuRite, indoor AcuRite, and weather.com. Percent error was also calculated.
- The Range was tested by measuring the highest and lowest values of data that can be accurately read by the sensor using an oven, deep freezer, shower, and baking soda. The items are labeled ground truth to show the lowest it could ha measured.
- The Resolution was tested by watching for the smallest change in input that can be accurately detected by sensor

All outputs were recorded and saved using Putty

AcuRite Thermometer Specifications

Outdoor Temperature Specification:

Temperature Range	-40 to 158 degrees Fahrenheit; -40 to 70 degrees Celsius
Temperature Accuracy	+/- 2 degrees Fahrenheit
Wireless Range	165 feet / 50 meters depending on home construction materials
Wireless Signal	433 MHz

Indoor Temperature Specification:

Indoor Temperature Range	32 to 122 degrees Fahrenheit; 0 to 50 degrees Celsius
Temperature Accuracy	+/- 2 degrees Fahrenheit
Indoor Humidity Range	1% to 99% Relative Humidity

Humidity and Reporting Specification:

Humidity Accuracy	+/- 5% from 0% to 10% Relative Humidity +/- 4% from 10% to 20% Relative Humidity +/- 3% from 20% to 80% Relative Humidity +/- 4% from 80% to 90% Relative Humidity +/- 5% from 90% to 100% Relative Humidity
Data Reporting	30 second updates

AcuRite Thermometer Specifications

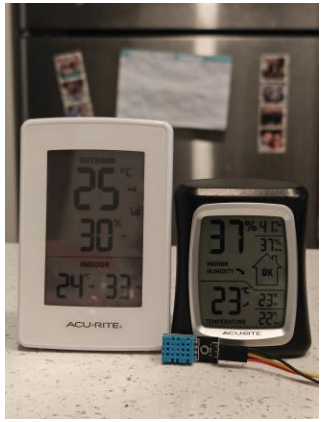
Indoor Temperature Range	32 to 122 degrees Fahrenheit; 0 to 50 degrees Celsius
Temperature Accuracy	+/- 2 degrees Fahrenheit
Indoor Humidity Range	16% to 98% Relative Humidity
Humidity Accuracy	+/- 5% from 0% to 10% Relative Humidity +/- 4% from 10% to 20% Relative Humidity +/- 3% from 20% to 80% Relative Humidity +/- 4% from 80% to 90% Relative Humidity +/- 5% from 90% to 100% Relative Humidity

Testing Humidity & Temperature

Testing Indoor Accuracy:

AcuRite Temperature	DHT-11 Temperature	AcuRite Humidity	DHT-11 Humidity
18°C to 23°C (black) 19°C to 24°C (White)	21.4°C to 24.7°C	37% to 41% (black) 33% to 39% (white)	32.2% to 41.1%

Thermostat Temperature (ground truth)
21°C



Testing Outdoor Accuracy @ 1:57pm:

AcuRite Temperature	DHT-11 Temperature	AcuRite Humidity	DHT-11 Humidity
22°C to 32°C (white)	25.0°C to 31.5°C	22% to 33% (white)	21.2% to 37.1%

Weather.com Temperature	Weather.com Humidity
23°C (ground truth)	31% (ground truth)

Testing Humidity & Temperature

Upper Temperature Range:

Oven Temperature (ground truth)	DHT-11 Temperature
176° C 104°C	61.8°C 61.9 °C

Upper Humidity Range:

Shower Humidity w/ AcuRite (ground truth)	DHT-11 Humidity
99%	100%

Lower Temperature Range:

Deep Freezer Temperature (ground truth)	DHT-11 Temperature
-22°C	-0.2°C

Lower Humidity Range:

Baking soda Humidity (ground truth)	DHT-11 Humidity
42%	46.8%

Results

Manufacture Specs:

- Accuracy - ±1°C and ±1%
- Range – Temperature: 0°C to 50°C
  Humidity: 20% to 90%
- Resolution - 1°C and 1%

Measurements Taken:

- Accuracy – Compared to the AcuRites and weather app the sensor was fairly accurate. There would be occasional outliers, and the longer you measured the less accurate it would get.

Percent Error = ((measurement – actual)/actual)*100

Indoor Precent error: Temp=1.9% to 17% Hum=11%

PE = (21.4-21)/21*100 to
PE = (24.7-21)/21*100

PE = (41.1-37)/37*100

Outdoor Percent error: Temp =8.6% to 36.9% Hum= 19%

PE = (25-23)/23*100 to
PE = (31.5-23)/23*100

PE = (37.1-31)/31*100

- Range: - Temperature: -0.2°C to 61.9°C
  Humidity: 46.8% to 100%

This is the range before the data is no longer accurately read.

- Resolution – The smallest change perceived is 0.1°C and 0.1%.

Ultrasonic Ranging Module

The ultrasonic ranging module consists of the ultrasonic transmitters, a receiver and a controller unit

The module uses an IO flip-flop to process a high-level signal of at least 10us. The module automatically sends out eight 40 khz and detects if there is a pulse signal return. If the signal returns, passing the high level, the high output IO duration is the time from the transmission of the ultrasonic wave to return of it.

Specifications

- Power Supply: DC 5V
- Working Current: 15mA
- Working Frequency: 40Hz
- Ranging Distance : 2cm – 400cm/4m
- Resolution : 0.3 cm
- Measuring Angle: 15 degree
- Trigger Input Pulse width: 10uS
- Dimension: 45mm x 20mm x 15mm

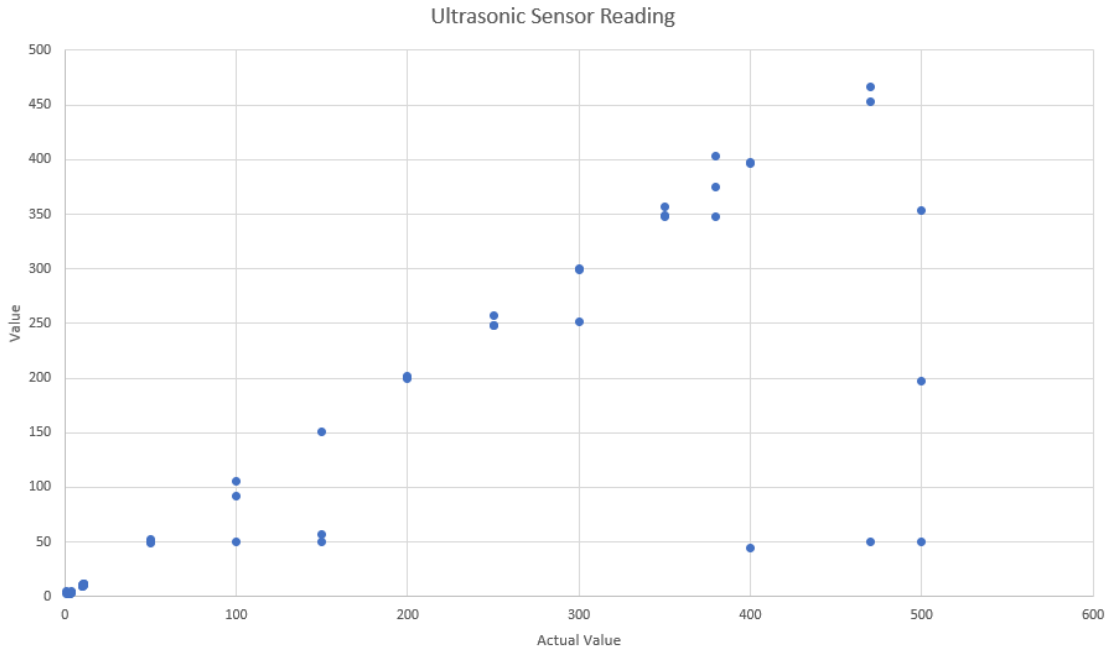
Important Characteristics

- Range
  - Range will be tested by measuring the highest and lowest values of the stimulus
- Resolution
  - Smallest change in input that can be accurately detected by sensor
- Accuracy
  - Will be determined by measuring output data with actual distance

Testing

Taking a portion of the values from sensor output and plotting them against the actual value recorded from a meter stick:

- 1 (cm)
- 2 (cm)
- 3 (cm)
- 4 (cm)
- 10 (cm)
- 50 (cm)
- 100 (cm)
- 150 (cm)
- 200 (cm)
- 250…
- 500

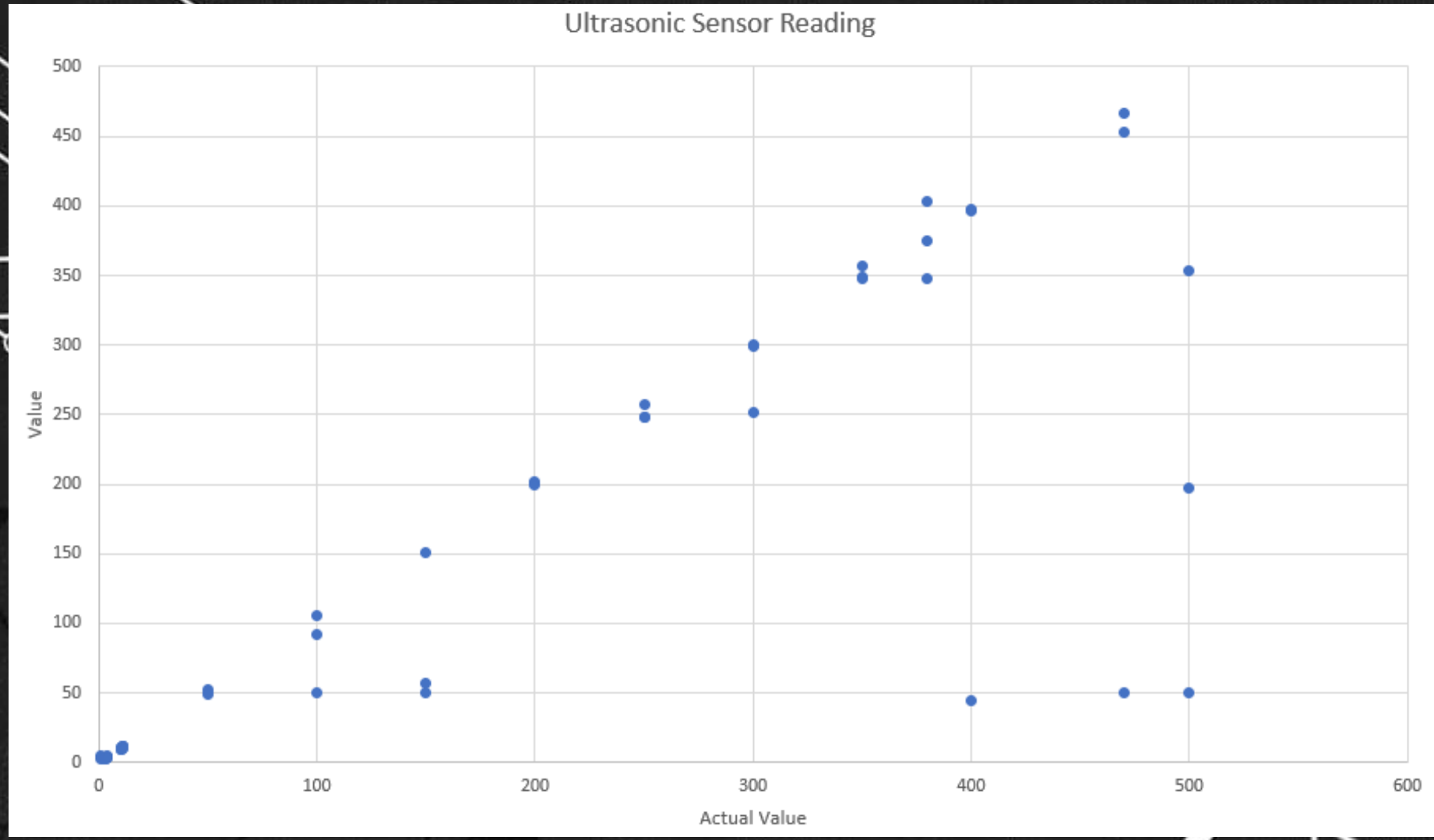


Excel data:
Actual vs. measured

1	2.78
1	4.41
2	2.45
2	2.78
2	3.33
3	3.1
3	2.78
3	3.1
4	4.09
4	3.76
4	3.66
4	4.41
4	4.09
10	9.71
10	9.72
10	9.62
10.5	10.43
10.5	9.97
10.5	10.31
11	11.12
11	10.31
11	10.67
11.3	11.12
11.3	12.07
11.3	11.02
50	52.88
50	48.53
50	50.31
100	106.12
100	91.84
100	50.31
150	150.66
150	56.97
150	50.1
200	200.67
200	201.34
200	199.64
250	248.45
250	247.97
250	257.07
300	251.6
300	300.5
300	299.22
350	349.12
350	347.88
350	356.79
380	374.59
380	348.1
380	403.05

How testing was conducted:

- made sure the sensor was high enough from the ground to stay within measuring angle


Ultrasonic Sensor Reading
Value
Actual Value
0
50
100
150
200
250
300
350
400
450
500
0
100
200
300
400
500
600

Results

Manufacturer Specs

- Range
  - 2cm – 400cm
- Resolution
  - 0.3 cm
- Accuracy
  - 1%-3%

Measured Specs

- Range
  - 3cm – 400 cm
- Resolution
  - 0.5 cm
- Accuracy
  - 1%-5%

Citations

- DHT 11 specs

https://components101.com/sensors/dht11-temperature-sensor

- Ultrasonic specs

https://www.seeedstudio.com/blog/2019/11/04/hc-sr04-features-arduino-raspberrypi-guide/

- MPU 6050 specs

https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf