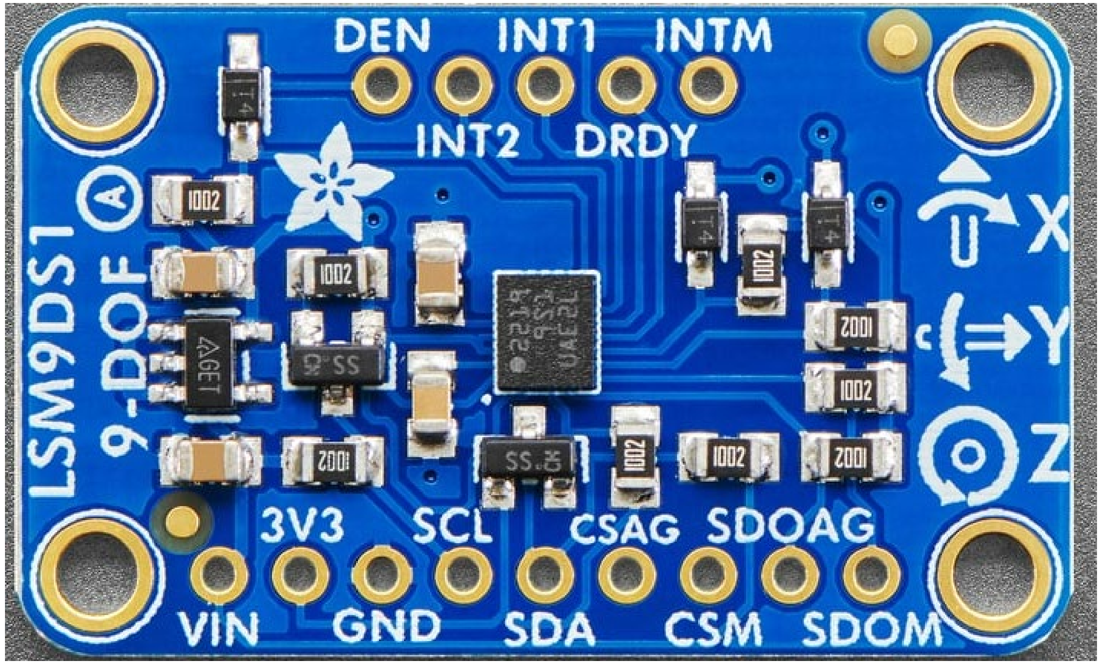
P524: Survey of Instrumentation and Laboratory Techniques
Week 5

9/17/2024

Week 5: sensors-1

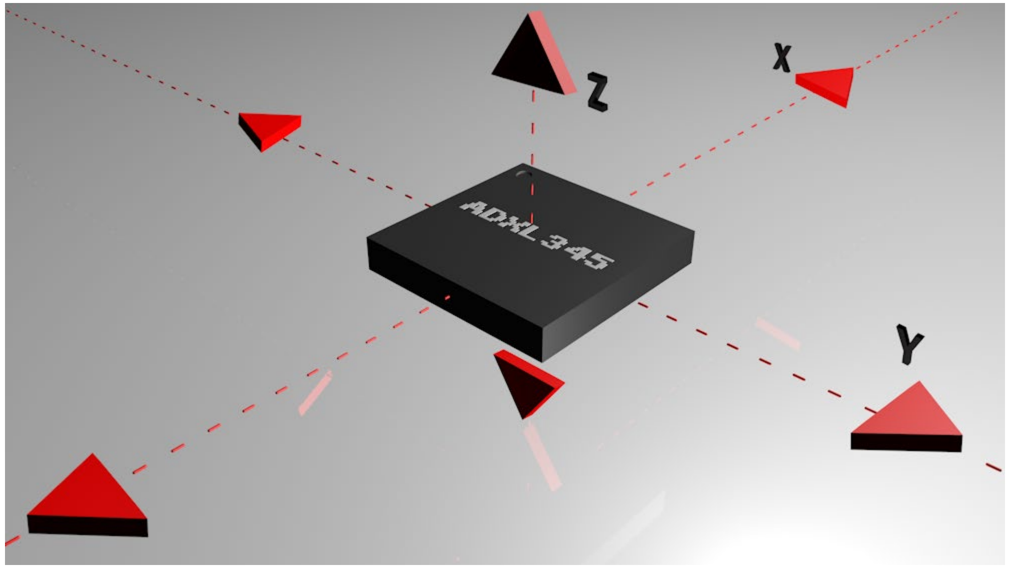


LSM9DS1 “9 axis” motion sensor:

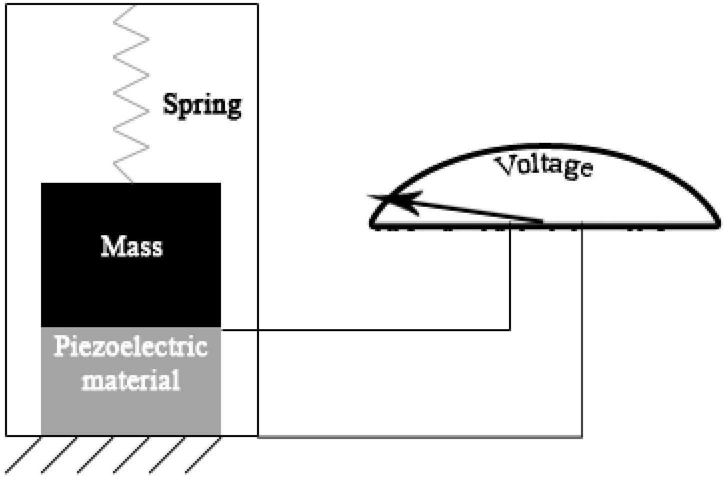
- Inertial Measurement Units (IMU)
- Sensor chip made by STMicroelectronics
- 9-axis iNEMO IMU:
    - 3D magnetometer,
    - 3D accelerometer,
    - 3D gyroscope
    - with I2C and SPI

Accelerometer

- Accelerometers are devices that measure acceleration, which is the rate of change of the velocity of an object. They measure in meters per second squared (m/s^2) or in G-forces (g). A single G-force for us here on planet Earth is equivalent to 9.8 m/s^2, but this does vary slightly with elevation (and will be a different value on different planets due to variations in gravitational pull). Accelerometers are useful for sensing vibrations in systems or for orientation applications.



- Accelerometers contain capacitive plates internally. Some of these are fixed, while others are attached to minuscule springs that move internally as acceleration forces act upon the sensor. As these plates move in relation to each other, the capacitance between them changes. From these changes in capacitance, the acceleration can be determined.
- Other accelerometers can be centered around piezoelectric materials. These tiny crystal structures output electrical charge when placed under mechanical stress (e.g. acceleration).
- MEMS (Micro-Electro-Mechanical systems) sensors leverage silicon's unique mechanical properties to integrate mechanical structures able to sense acceleration, rotation, angular rate, vibration, displacement, heading, and other



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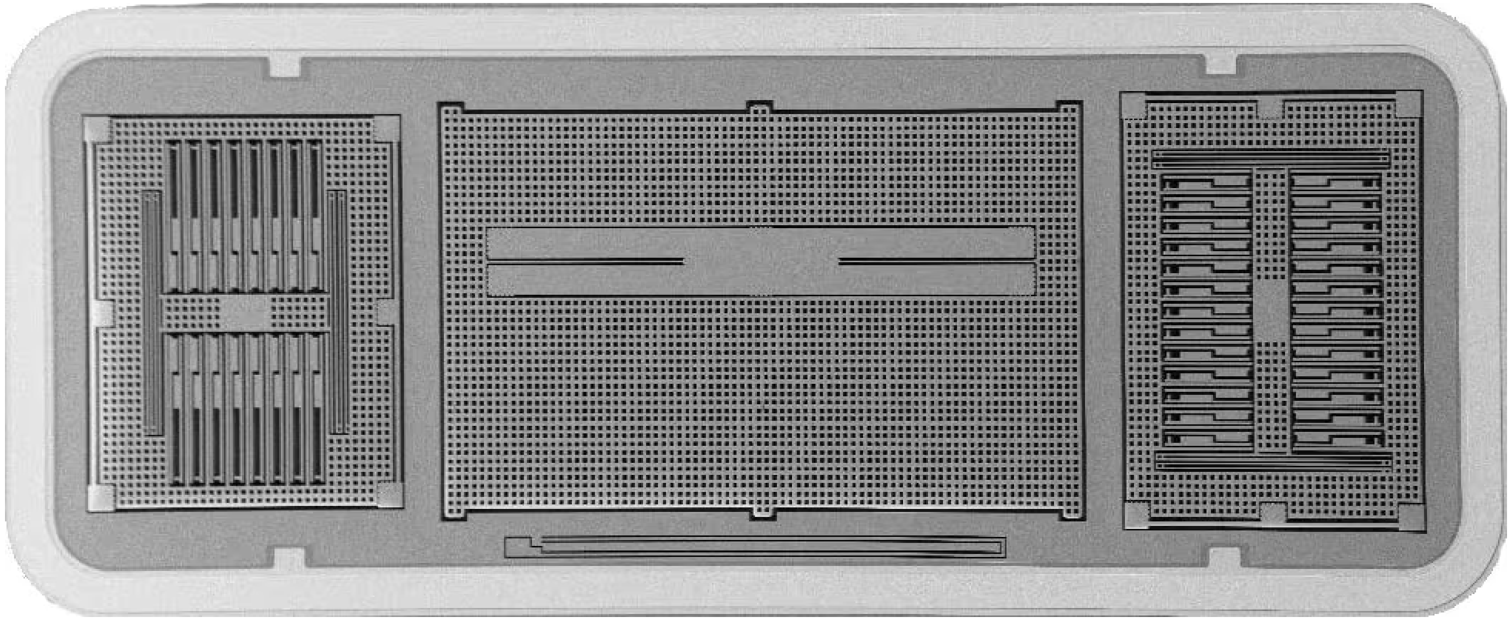
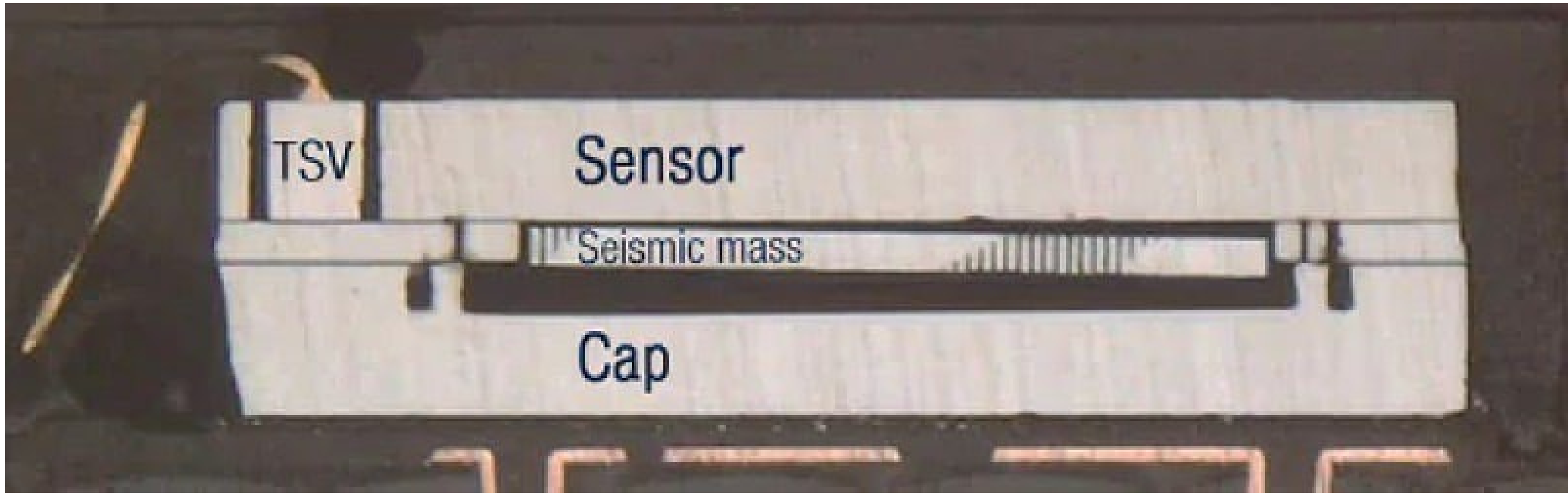
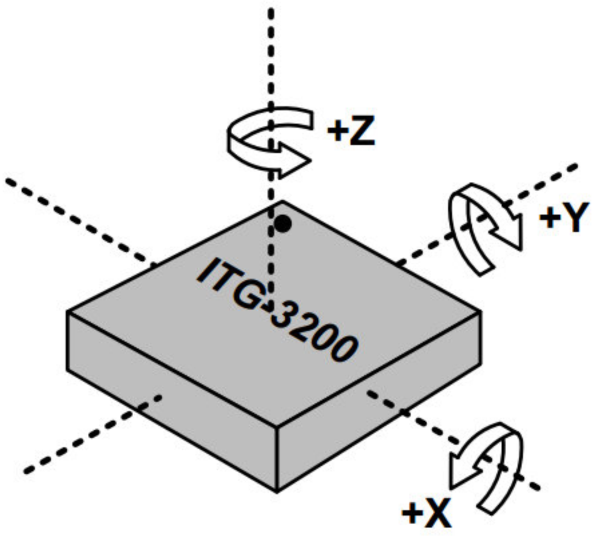
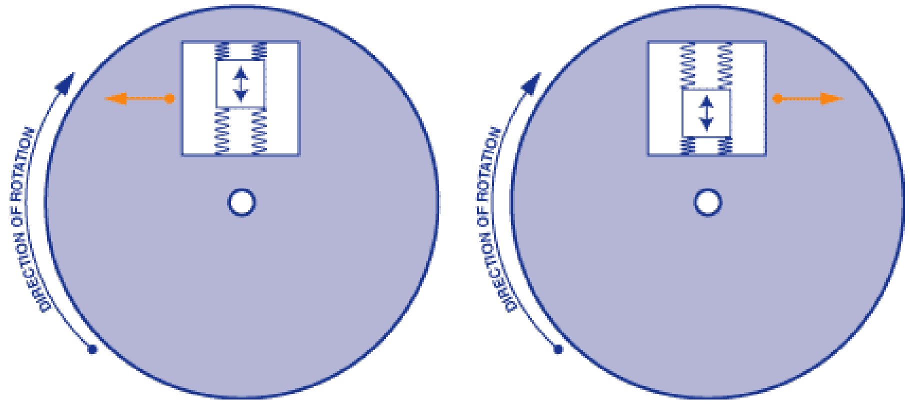




Gyroscope

- Gyroscopes, or gyros, are devices that measure or maintain rotational motion. MEMS (microelectromechanical system) gyros are small, inexpensive sensors that measure angular velocity. The units of angular velocity are measured in degrees per second (°/s) or revolutions per second (RPS). Angular velocity is simply a measurement of speed of rotation.
- A triple axis MEMS gyroscope, similar to the one pictured on the right (ITG-3200), can measure rotation around three axes: x, y, and z. Some gyros come in single and dual axis varieties, but the triple axis gyro in a single chip is becoming smaller, less expensive, and more popular.
- Gyros are often used on objects that are not spinning very fast at all. Aircrafts (hopefully) do not spin. Instead they rotate a few degrees on each axis. By detecting these small changes gyros help stabilize the flight of the aircraft. Also, note that the acceleration or linear velocity of the aircraft does not affect the measurement of the gyro. **Gyros only measure angular velocity**.
- How does the MEMS gyro detect angular velocity? The gyroscope sensor within the MEMS is tiny (between 1 to 100 micrometers, the size of a human hair). When the gyro is rotated, a small resonating mass is shifted as the angular velocity changes. This movement is converted into very low-current electrical signals that can be amplified and read by a host microcontroller.





Magnetometers

Hall effect magnetometer

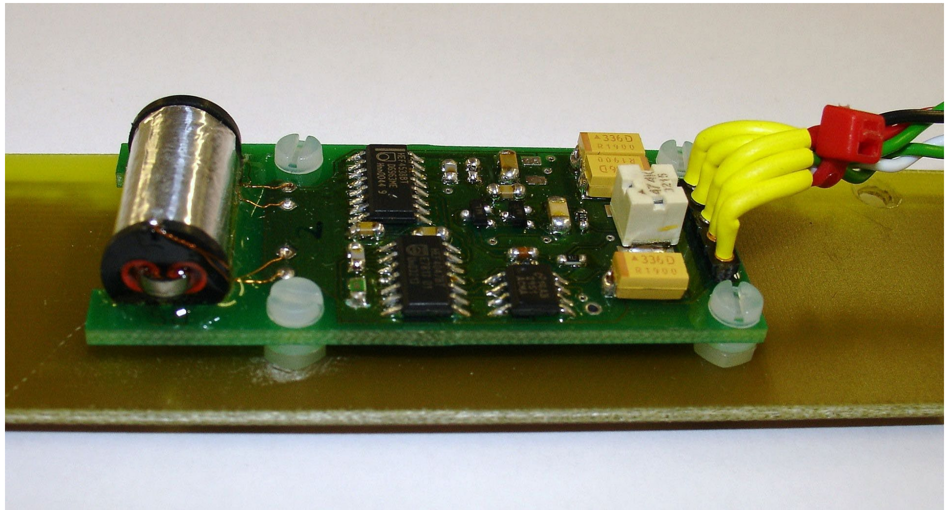
- The most common magnetic sensing devices are solid-state Hall effect sensors. These sensors produce a voltage proportional to the applied magnetic field and also sense polarity. They are used in applications where the magnetic field strength is relatively large, such as in anti-lock braking systems in cars, which sense wheel rotation speed via slots in the wheel disks.

Magnetoresistive devices

- These are made of thin strips of Permalloy, a high magnetic permeability, nickel-iron alloy, whose electrical resistance varies with a change in magnetic field. They have a well-defined axis of sensitivity, can be produced in 3-D versions and can be mass-produced as an integrated circuit. They have a response time of less than 1 microsecond and can be sampled in moving vehicles up to 1,000 times/second. They can be used in compasses that read within 1°, for which the underlying sensor must reliably resolve 0.1°.

Fluxgate magnetometer

A fluxgate magnetometer consists of a small magnetically susceptible core wrapped by two coils of wire. An alternating electric current is passed through one coil, driving the core through an alternating cycle of magnetic saturation; i.e., magnetised, unmagnetised, inversely magnetised, unmagnetised, magnetised, and so forth. This constantly changing field induces a voltage in the second coil which is measured by a detector.



Gyroscope Datasheets

- https://learn.adafruit.com/comparing-gyroscope-datasheets

- L3GD20 3 Axis MEMS Gyroscope - ST
- FXAS21002C 3 Axis MEMS Gyroscope - NXP
- LSM9DS0 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - ST
- LSM9DS1 9 Axis* MEMES Sensor (Acce + Mag + Gyro) - ST
- MPU-9250 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - Invensense
- BMI055 6 Axis MEMS Sensor (Accel + Gyro) - Bosch (Used in the BNO055)

	Dynamic Range (dps)	ADC
L3GD20	250/500/2000	16 bits
FXAS21002C	250/500/1000/2000	16 bits
LSM9DS0	245/500/2000	16 bits
LSM9DS1	245/500/2000	16 bits
MPU-6250	250/500/1000/2000	16 bits
BMI055	125/250/500/1000/2000	16 bits

LM9DS1

G_FS	Angular rate measurement range			±245		dps
				±500		
				±2000		
LA_So	Linear acceleration sensitivity	Linear acceleration FS = ±2 *g*		0.061		m*g*/LSB
		Linear acceleration FS = ±4 *g*		0.122		
		Linear acceleration FS = ±8 *g*		0.244		
		Linear acceleration FS = ±16 *g*		0.732		
M_GN	Magnetic sensitivity	Magnetic FS = ±4 gauss		0.14		mgauss/ LSB
		Magnetic FS = ±8 gauss		0.29		
		Magnetic FS = ±12 gauss		0.43		
		Magnetic FS = ±16 gauss		0.58		
G_So	Angular rate sensitivity	Angular rate FS = ±245 dps		8.75		mdps/ LSB
		Angular rate FS = ±500 dps		17.50		
		Angular rate FS = ±2000 dps		70		
LA_TyOff	Linear acceleration typical zero-g level offset accuracy(2)	FS = ±8 *g*		±90		m*g*
M_TyOff	Zero-gauss level (3)	FS = ±4 gauss		±1		gauss
G_TyOff	Angular rate typical zero-rate level (4)	FS = ±2000 dps		±30		dps
M_DF	Magnetic disturbance field	Zero-gauss offset starts to degrade			50	gauss
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed
2. Typical zero-*g* level offset value after soldering
3. Typical zero-gauss level value after test and trimming
4. Typical zero rate level offset value after MSL3 preconditioning

Week 5: sensors-2

Distance Measurement:

VL6180X "Time of Flight Distance Ranging Sensor"

- Micro-LIDAR (light detection and Ranging) distance sensor
  - Range: 5-100 mm
- Lux sensor
- I2C communication, I2C address is **0x29**

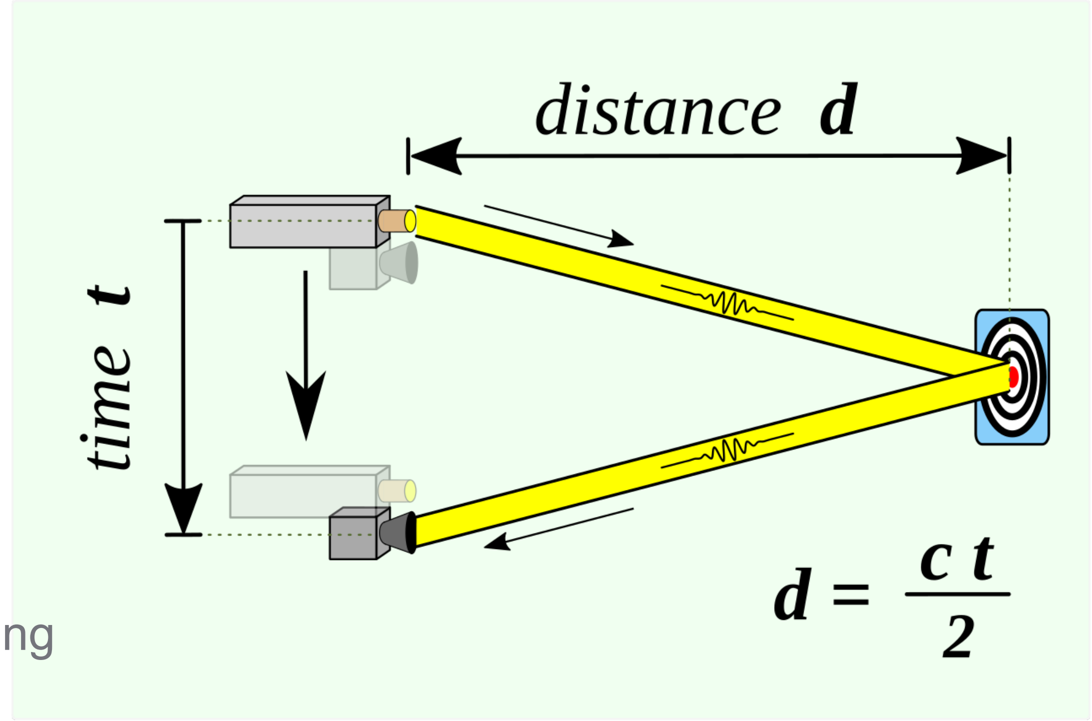
VL6180 sensor chip

VL6180X 3 in 1 proximity sensor

Based on FlightSense™

- The VL6180 from STMicroelectronics is a 3-in-1 package that combines
  - an IR emitter (850 nm infrared laser),
  - a range sensor, and
  - an ambient light sensor

  communicate via an I^2C interface.

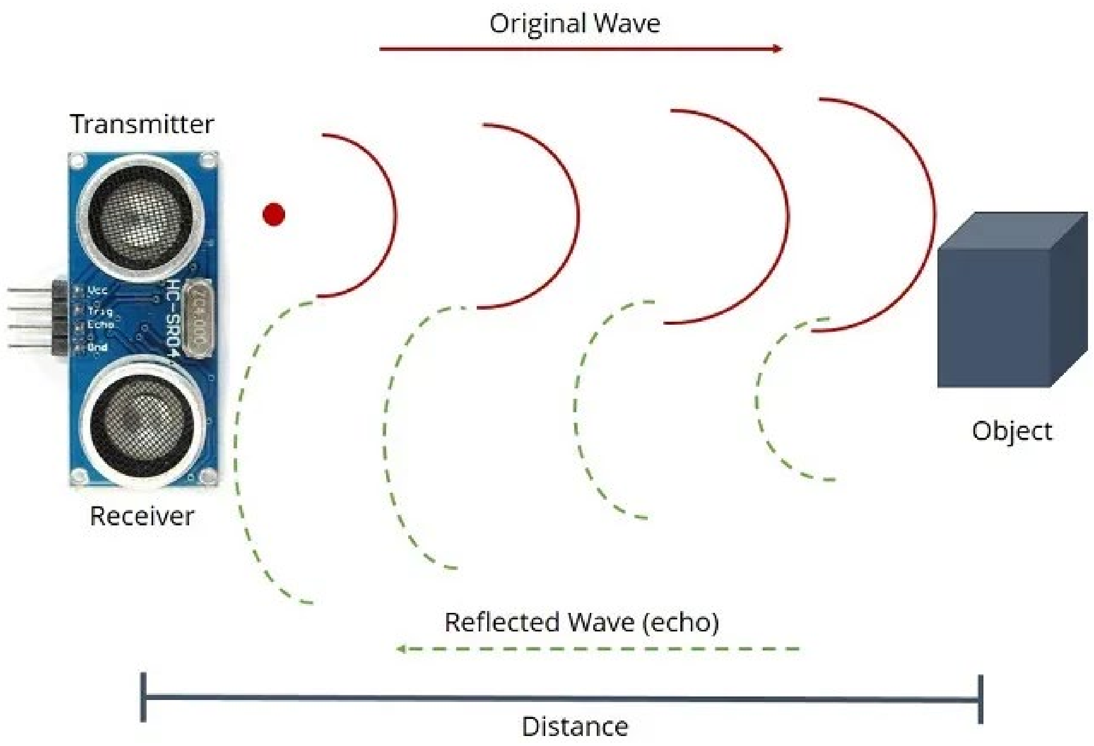


- Fast, accurate distance ranging
  - Measures absolute range from 0 to above 10 cm (ranging beyond 10cm is dependent on conditions)
  - Independent of object reflectance
  - Ambient light rejection
  - Cross-talk compensation for cover glass

Unlike most distance sensors that rely on reflected light intensity or reflected angles to determine range, the VL6180 uses a precise clock to measure the time it takes light to bounce back from a surface. This offers the ToF Range Finder and VL6180 a great benefit over other methods because it can be much more accurate and more immune to noise.

Difference Types of Distance Sensors

- Ultrasonic Sensor, also known as the Sonar sensor
  - Emitting high-frequency *sound waves*
  - The wave is reflected by an object nearby.
  - The receiver pick up the reflected wave.
  - Distance = ½*(time delay/velocity of sound).



Advantages of Ultrasonic Sensors

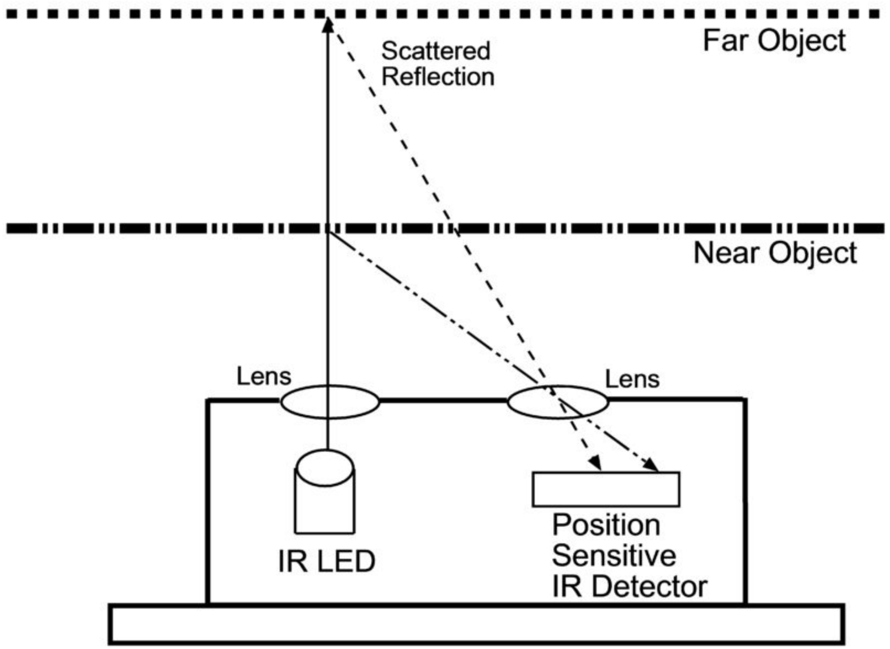
•Not affected by object colour and transparency as it detects distance through sound waves
•Works well in places that are dim
•Tend to consume lower current/power

Disadvantages of Ultrasonic Sensors

•Limited detection range
•Low resolution and slow refresh rate, making it not suitable for detection of fast-moving targets
•Unable to measure the distance of objects that have extreme textures/surfaces

Infrared Distance Sensors

- An IR LED emitter lens that emits a light beam
- A position-sensible photodetector (PSD) where the reflected beam will fall onto



Advantages of IR Sensors

•Small form factor; Common IR sensors like the ones from Sharp tend to be smaller in size
•Applicable for daytime and nighttime usages
•Secured communication through a line of sight
•Able to measure the distance of objects that have complex surfaces unlike ultrasonic sensors

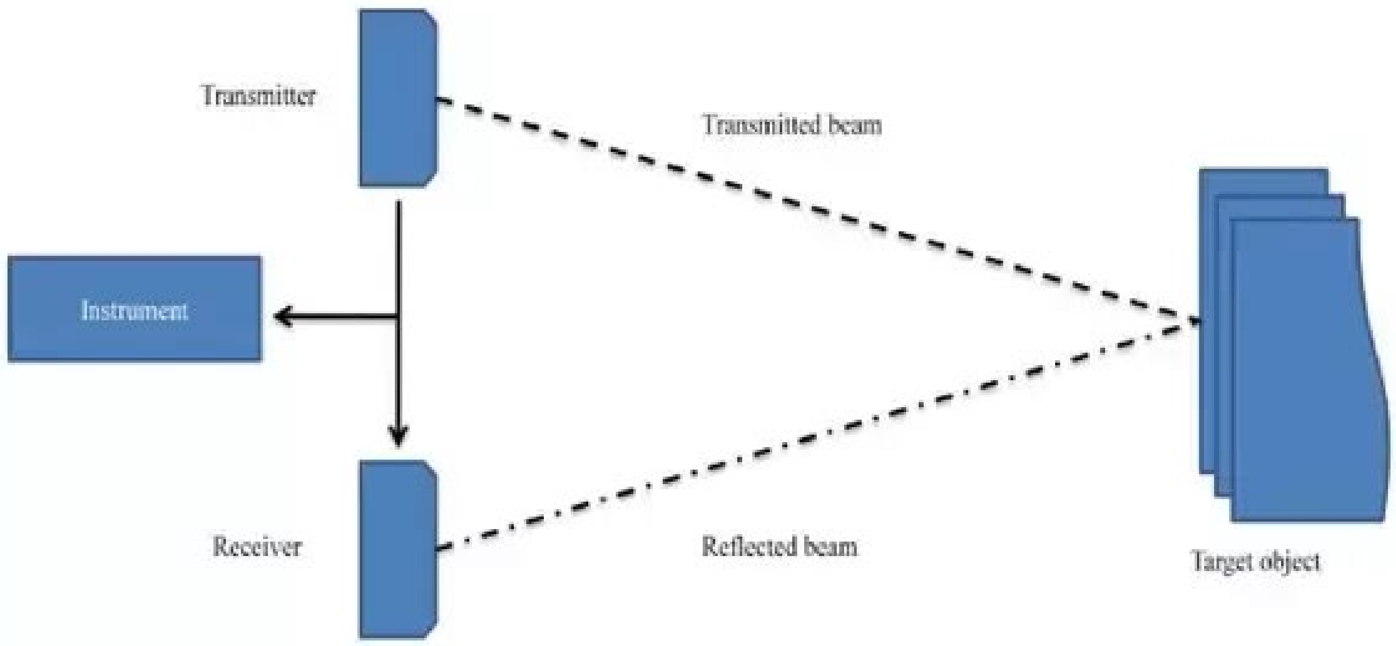
Disadvantages of IR sensors

•Limited measurement range
•Affected by environmental conditions and hard objects

IR vs Ultrasonic distance sensors

Type	IR Sensor	Ultrasonic Sensor
What It Does	Measure distance through reflected light waves	Measure distance through reflected sound waves
How It Measures	Triangulation: Angle of a reflected IR beam is measured	Time taken between transmitting and receiving sound waves are recorded
Human Interactions	Invisible to the naked eye	Unhearable
Object Requirements	Suitable to be used to measure complex objects	Not suitable to measure objects with complex surfaces

Laser Distance Sensors: LIDAR



- **Advantages of LiDAR**
- High measurement range and accuracy
- Ability to measure 3D structures
- Fast update rate; suitable for fast-moving objects
- Small wavelengths as compared to sonar and radar; good at detecting small objects
- Applicable for usage in the day and night

- **Disadvantages of LiDAR**
- Higher cost as compared to ultrasonic and IR
- Harmful to the naked eye; higher-end LiDAR devices may utilize stronger LiDAR pulses which may affect the human eye

LED Time-Of-Flight Distance Sensors

Time-of-flight sensors work similarly to LiDAR sensors, where:

1. The transmitter on the time-of-flight device emits IR waves towards the target object
2. The wave is reflected back upon reaching the target object
3. Distance is then calculated by using the speed of light in air and the time between sending/receiving of the signal

With time-of-flight technology, it provides significant benefits over the other distance sensing methods, including a wider range, faster readings, and greater accuracy.

Advantages of Time-of-Flight Sensors

- Such technology offers high measurement range with accuracy
- 3D imaging capable
- Used in a wide variety of applications due to its ability to identify large objects
- **Disadvantages of Time-of-Flight Sensors**
- Higher costs in general
- Z-depth resolution is still poor with general systems offering a 1cm Z-resolution

Comparison of different distance sensing techniques

Type	Ultrasonic	IR	LIDAR	ToF
Suitablility for Long Range Sensing	No	No	Yes	Yes
High reading frequency	No	No	Yes	Yes
Cost	Low	Low	High	Moderate
Suitability to use for complex objects	No	Yes	Yes	Yes
Sensitive to external conditions	Yes	No	No	No
3D imaging compatible	No	No	Yes	Yes

Both ultrasonic and IR distance sensors are more suited for Arduino projects that require shorter range sensing. While LiDAR and Time-of-flight sensors would be recommended for those that are looking for higher sensing capabilities and 3D imaging!