Electronics for IoT

Smart Sensors

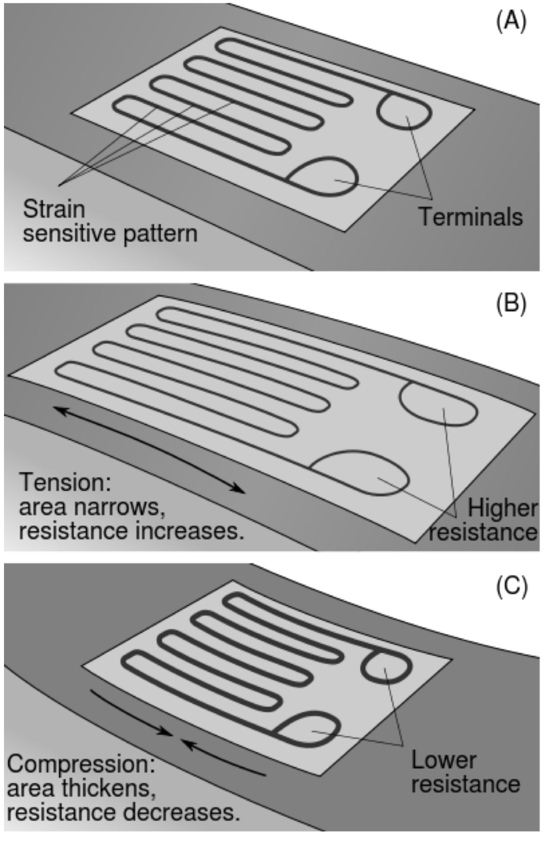
Bernhard E. Boser
University of California, Berkeley
boser@eecs.berkeley.edu

Smart Sensor

- “Catchy” term for a sensor that detects a physical quantity and generates digital output (number) ready to work with. E.g.
  – Current in [mA] (INA219)
  – Temperature in degrees Celsius
  – Pressure in mBar
  – Relative humidity in percent
  – Distance in meters (LIDAR)
- Can be quite involved
  – E.g. temperature calibration
- Usually interfaced via I2C (SPI, OneWire, UART, …)
  – Software driver

“Not” Smart Sensor

- Transduce physical quantity into something “electrical”
- E.g. strain gauge:
  – Mechanical strain → resistance change
- User builds interface, e.g.
  – Convert resistance change to voltage
  – Voltage to digital (ADC)
  – Implement error correction,
    e.g. temperature compensation
- Later in EE49
  – Today’s focus is “smart”

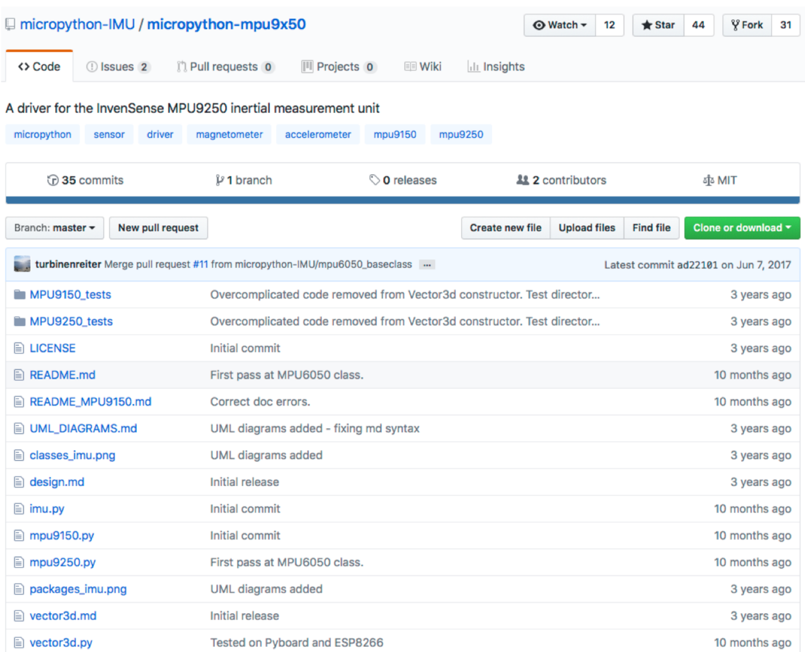


Parts

- Many
- Keep getting better
  - Lower power
  - Better accuracy
  - Driven by automotive and consumer (smartphone) markets
  - Tactical and industrial units
- Examples:
  - InvenSense MPU9250, ICM-20848
  - Bosch BNO055

Interfacing

- I2C Bus
- Driver
  - https://github.com/micropython-IMU/micropython-mpu9x50



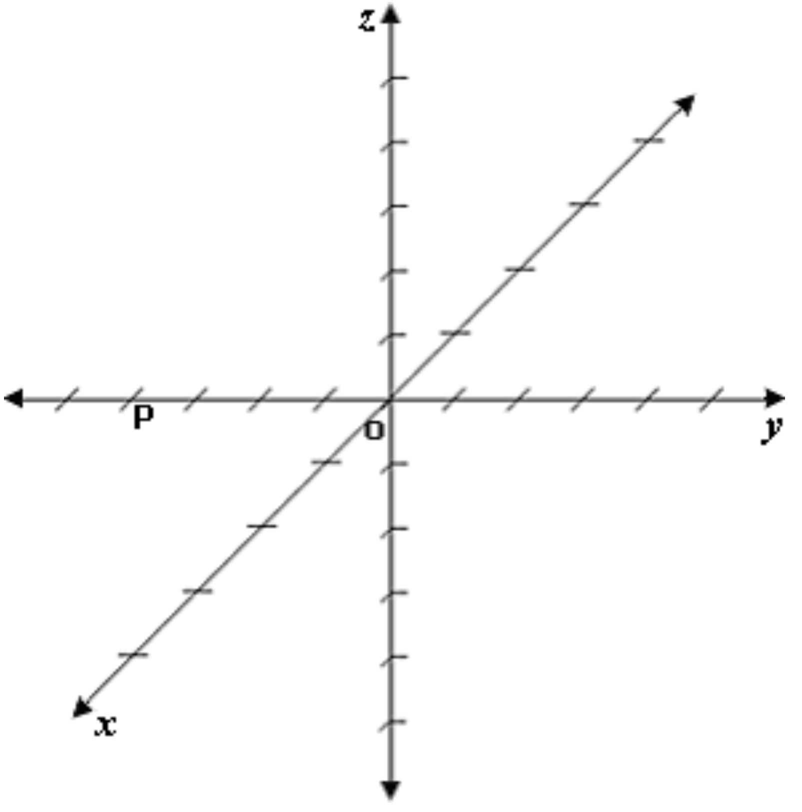
MPU9250 MicroPython Driver

Example assuming an MPU9250 connected to 'X' I2C interface on the Pyboard:

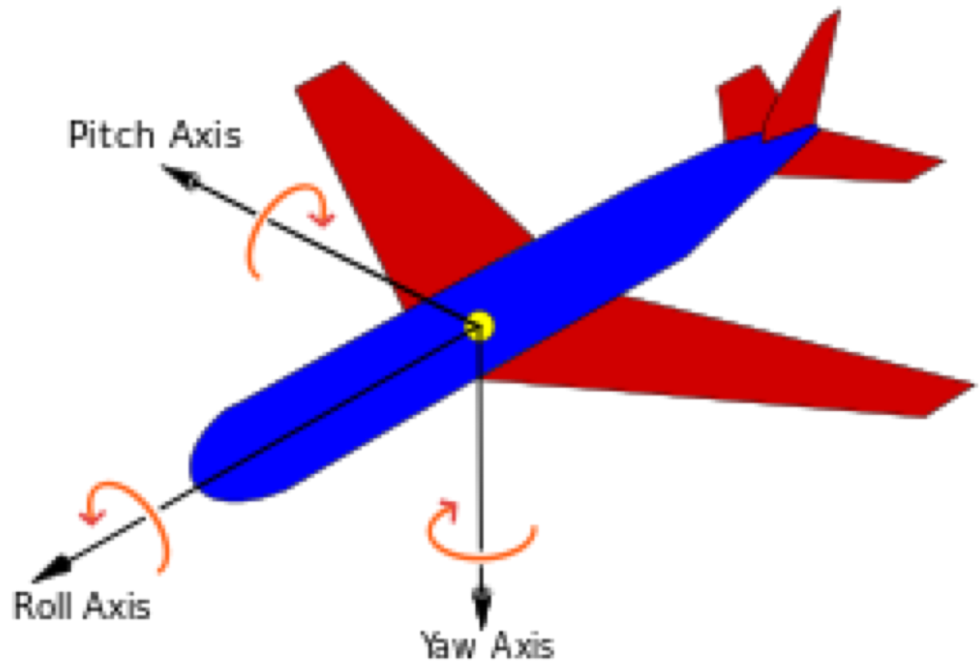
```
from mpu9250 import MPU9250
imu = MPU9250('X')
print(imu.accel.xyz)
print(imu.gyro.xyz)
print(imu.mag.xyz)
print(imu.temperature)
print(imu.accel.z)
```

9 Degrees of Freedom Inertial Sensor

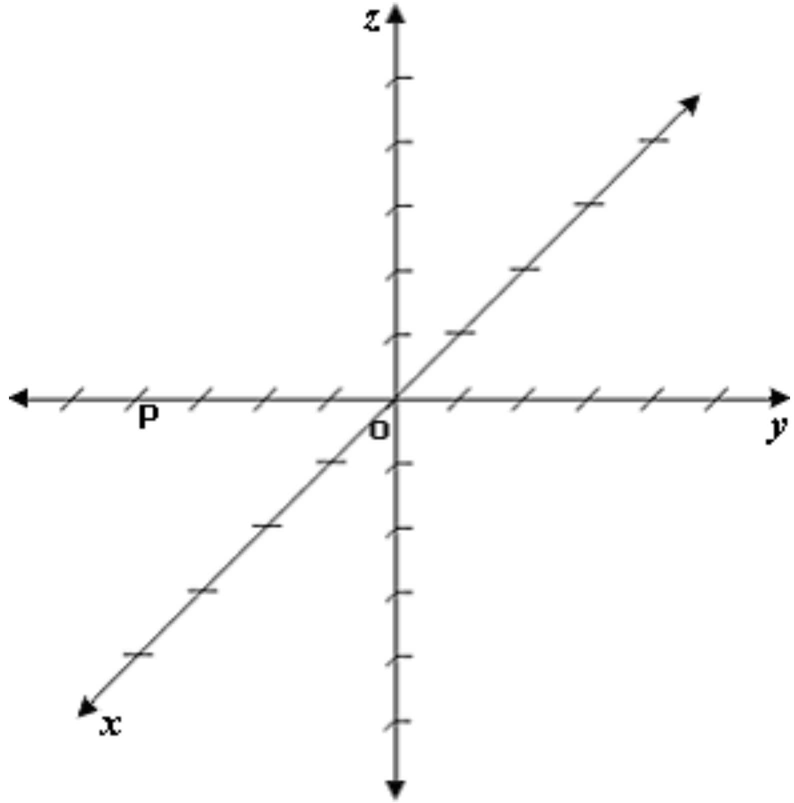
3D Acceleration



Angular Rate



Magnetometer

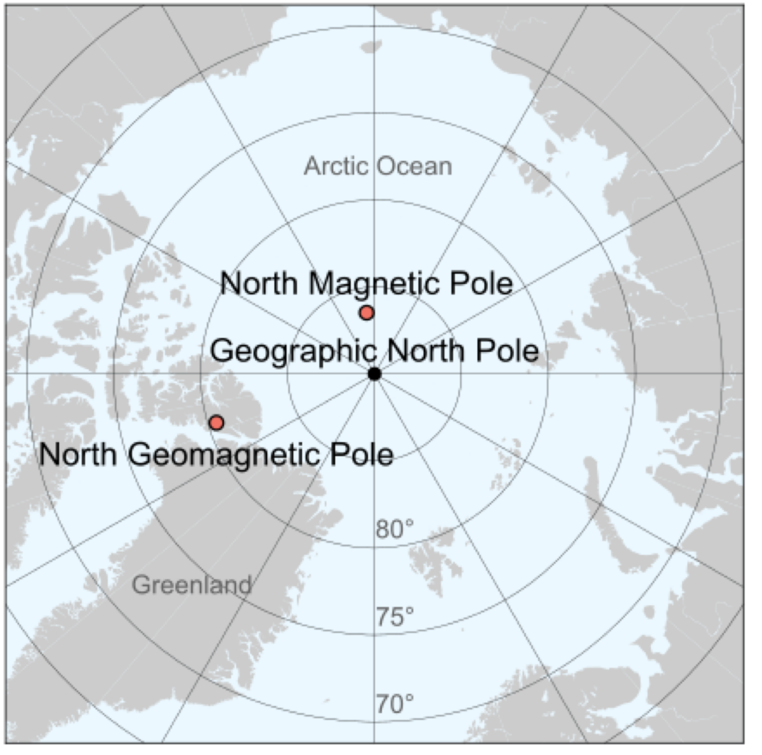


What can we do with it?

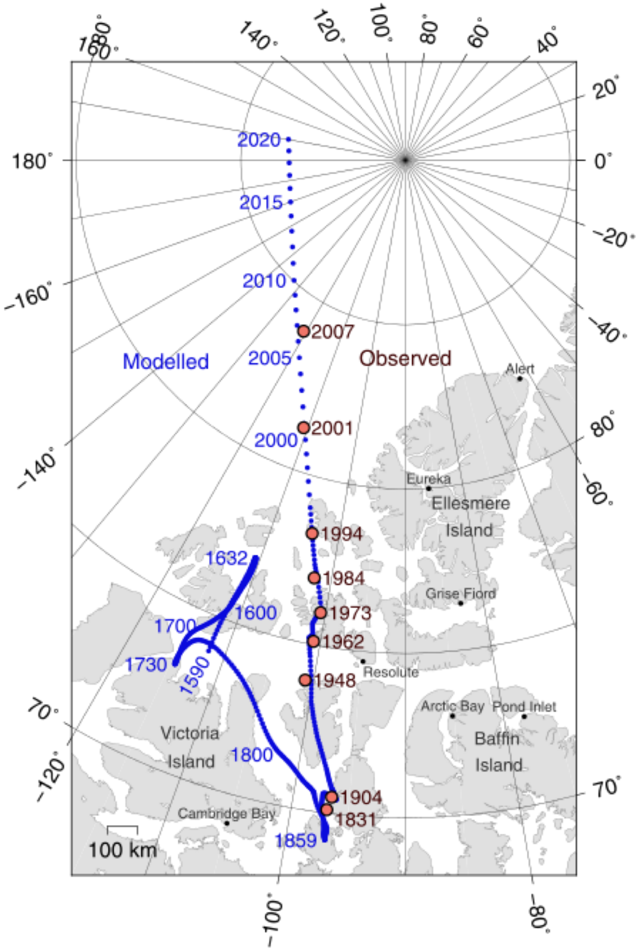
- Examples:
  - Compass
  - Inclinometer
  - Navigation

Compass


N
NW
NE
W
E
SW
SE
S

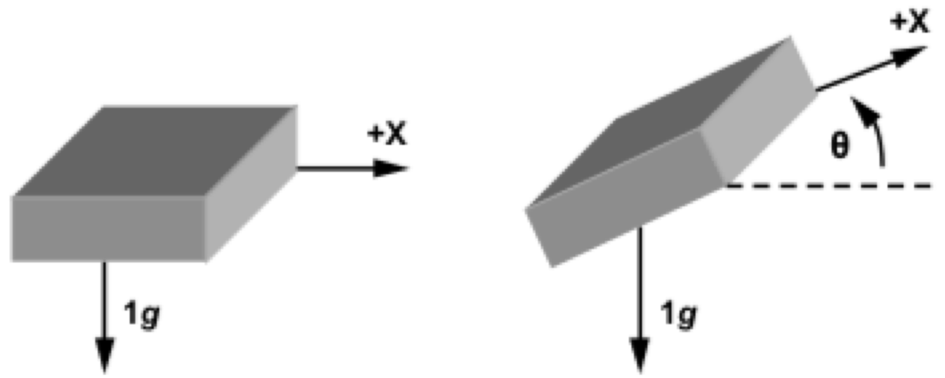

Arctic Ocean
North Magnetic Pole
Geographic North Pole
North Geomagnetic Pole
80°
Greenland
75°
70°

Magnetic Heading Errors



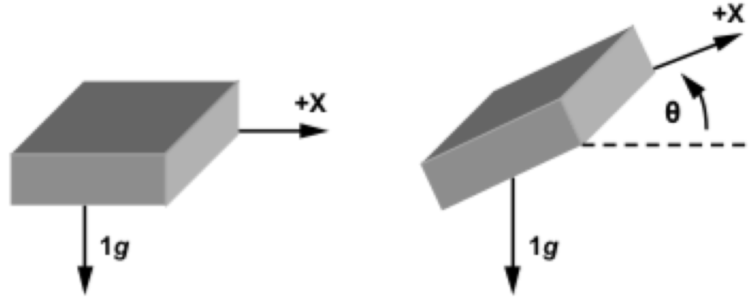
- 25 … 65 μTesla
  - vs ~ 1 Tesla (rare earth magnet)
- Magnetic declination
  - Magnetic north != true north
  - Berkeley: ~ 14° 16’ E
- Bigger problem:
  - Stray magnetic fields
  - Earth magnetic field distortion
  - Dominates in urban environments
  - Requires calibration

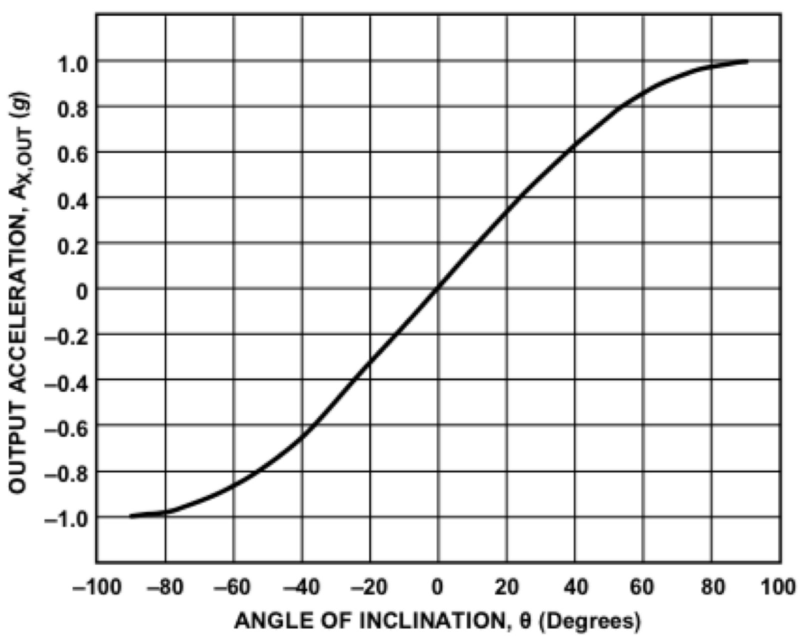
Inclinometer (Tilt)



http://www.analog.com/media/en/technical-documentation/application-notes/AN-1057.pdf

Inclinometer

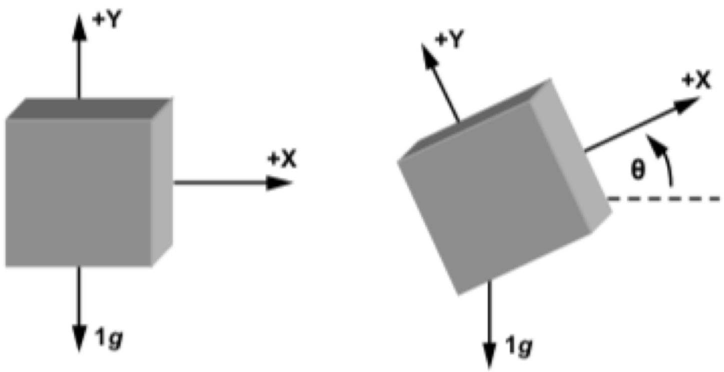


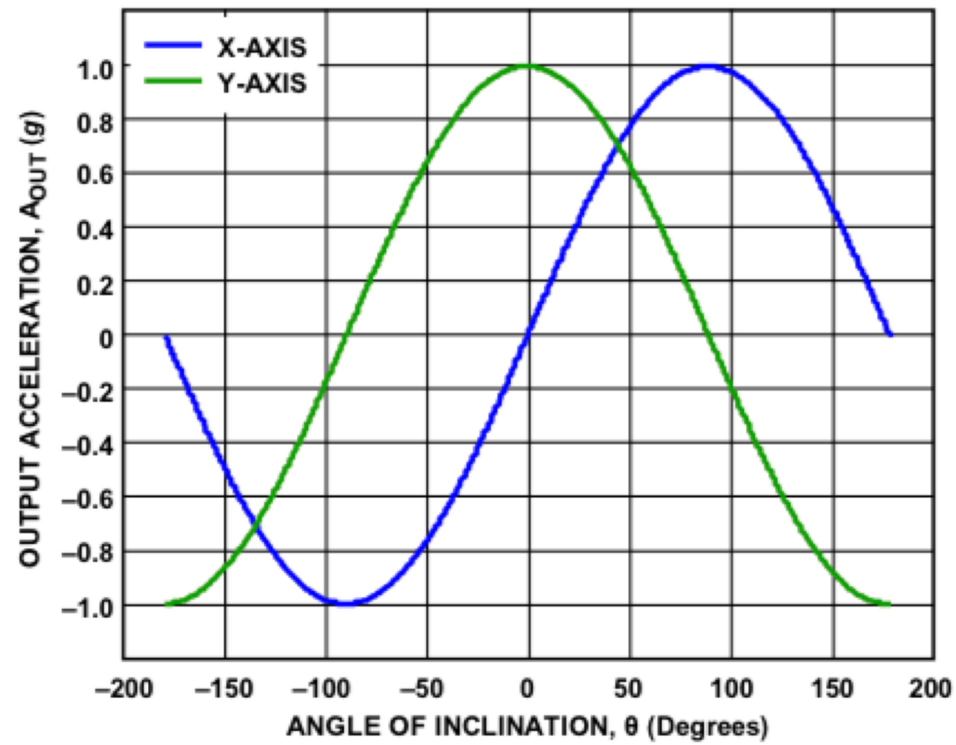


$$A_{X,OUT}\,[g] = 1\,g \times \sin(\theta)$$

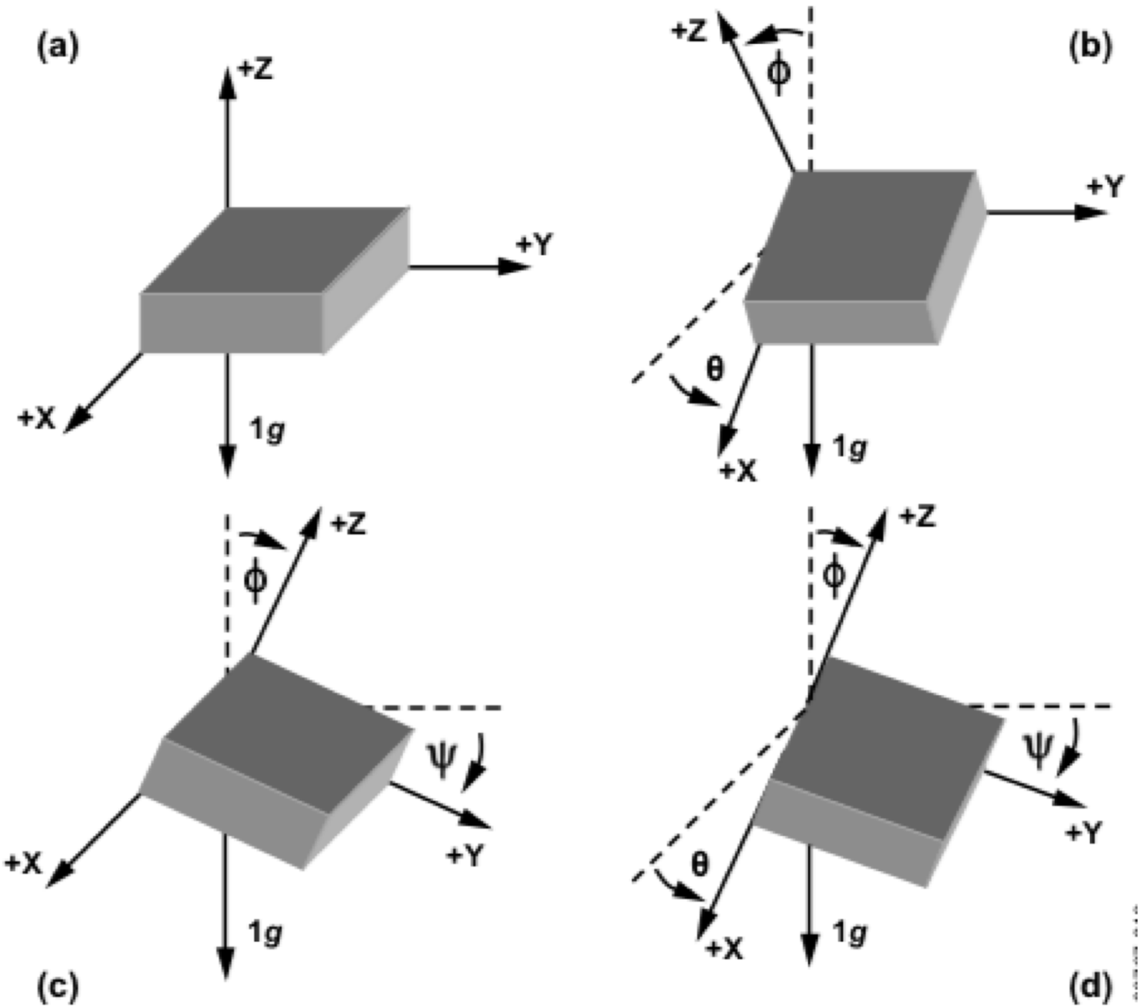
http://www.analog.com/media/en/technical-documentation/application-notes/AN-1057.pdf

Dual Axis Tilt Sensor





Triple Axis Tilt Sensor



Disturbances

- Moving platform (e.g. quadcopter)
  - Additional sources of acceleration
  - Not just gravity
  - → Incorrect tilt calculation

Solution: Sensor Fusion

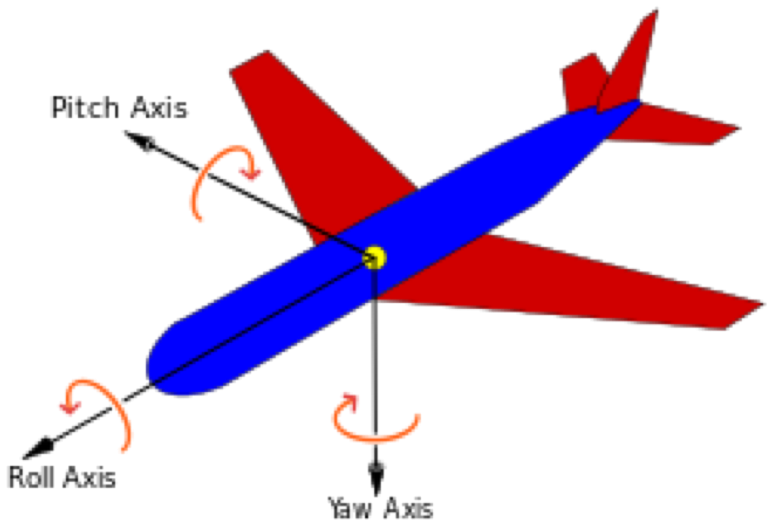
- Gyroscope
  - Compute angle from rate
  - Problem:
- Fix
- Fusion
  - Complementary filter
  - Kalman filter

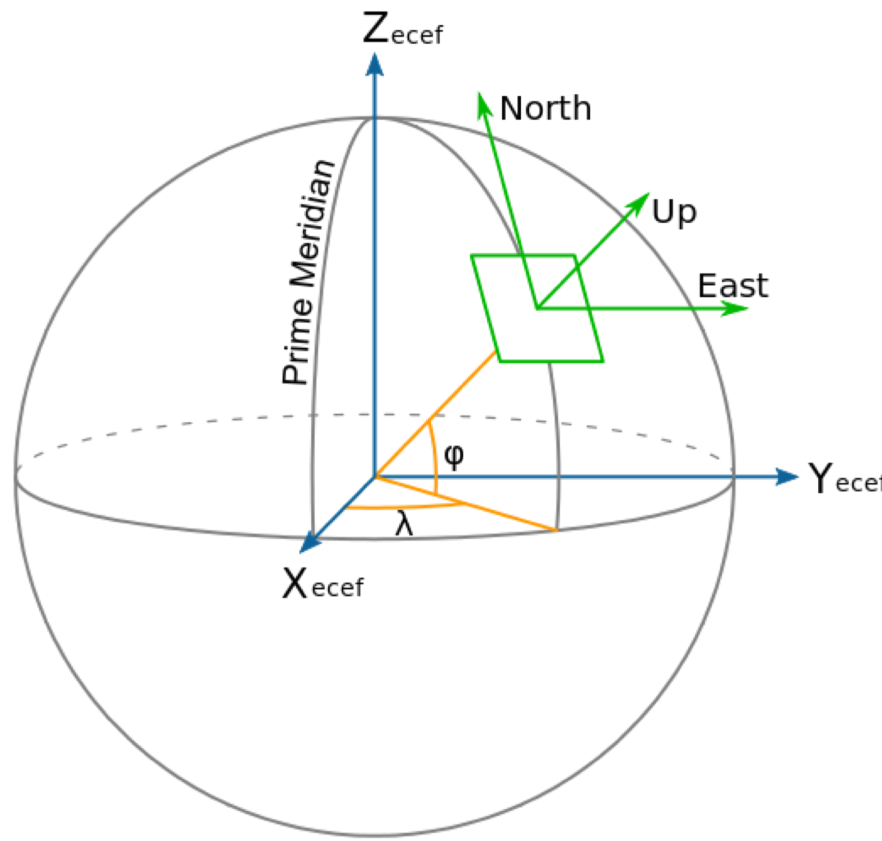
Complementary Filter

Navigation

- Principle:
  - Gyroscope → Heading
  - Accelerometer → Distance
- Challenges
  - Relative
  - Integration → drift
    - Fuse with GPS
  - Coordinate systems

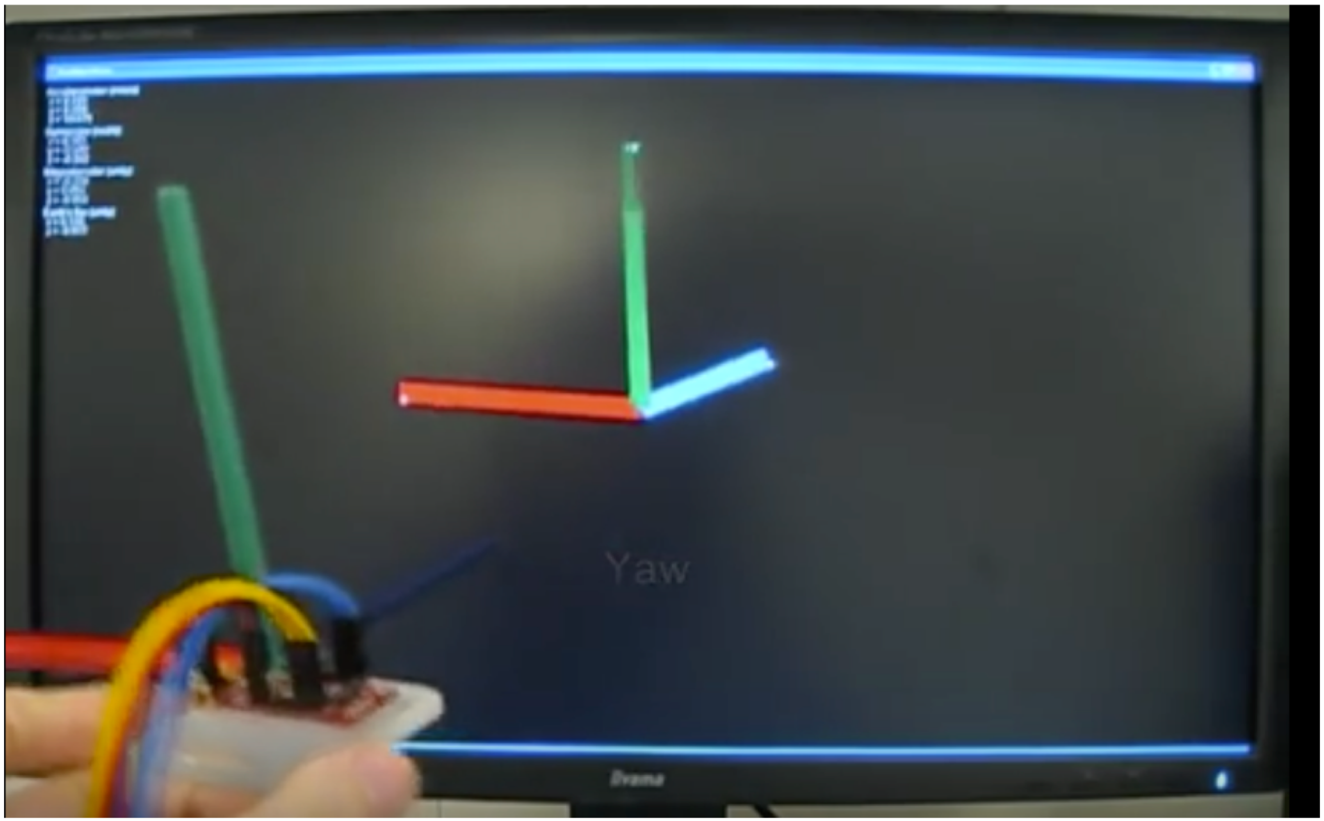
Navigation Coordinates





Attitude and Heading Reference System (AHRS)

- https://www.youtube.com/watch?v=fOSTOnQzZCI



Accelerometer, Gyroscope, Magnetometer Fusion

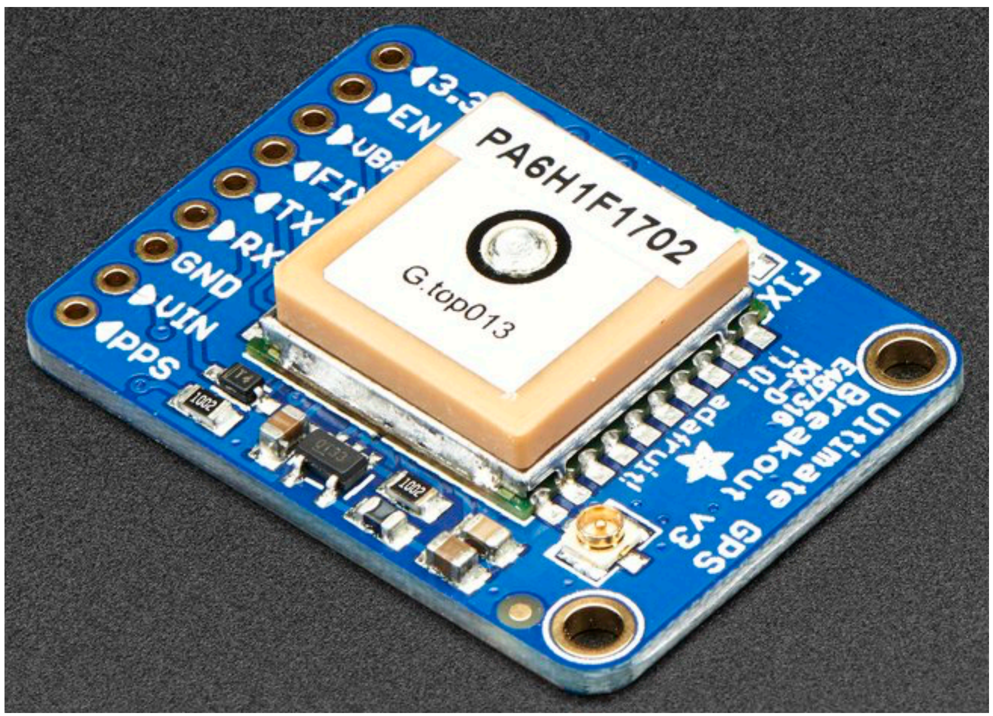
- http://scottlobdell.me/2017/03/video-tutorials-outlining-inertial-measurement-unit-imu-implementation-sensor-fusion-gps/

Accelerometer, Gyroscope, Magnetometer Fusion

- IMU outputs →
  a) Pitch, yaw, roll angles
  b) Absolute acceleration North, East, Down
  c) Correct for gravity
- MicroPython Library
  – https://github.com/micropython-IMU/micropython-fusion
- GPS fusion for absolute position
- References
  – https://en.wikipedia.org/wiki/Inertial_navigation_system
  – http://www.olliw.eu/2013/imu-data-fusing/
  – http://scottlobdell.me/2017/03/video-tutorials-outlining-inertial-measurement-unit-imu-implementation-sensor-fusion-gps/

GPS

- Many modules to choose from



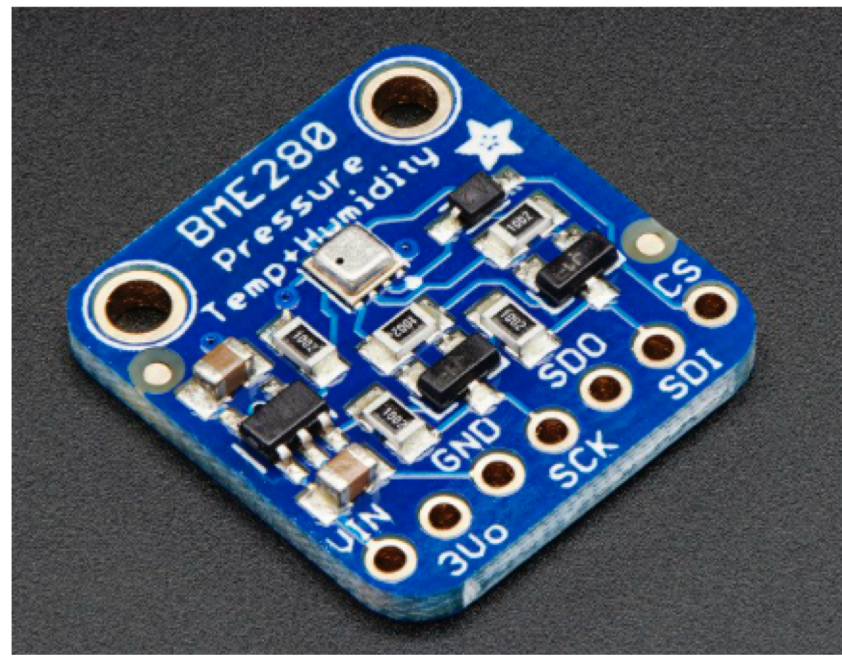
Smart Sensor Choices

- Lots … search
- Examples …

Temperature / Pressure / Humidity

- E.g. BME280
  - Temperature: ± 0.5 deg C
  - Pressure: 0.2 Pa rms (1.7cm)
  - Humidity: ± 3%

BME280
Combined humidity and pressure sensor



- MicroPython driver

- BME680 adds VOCs

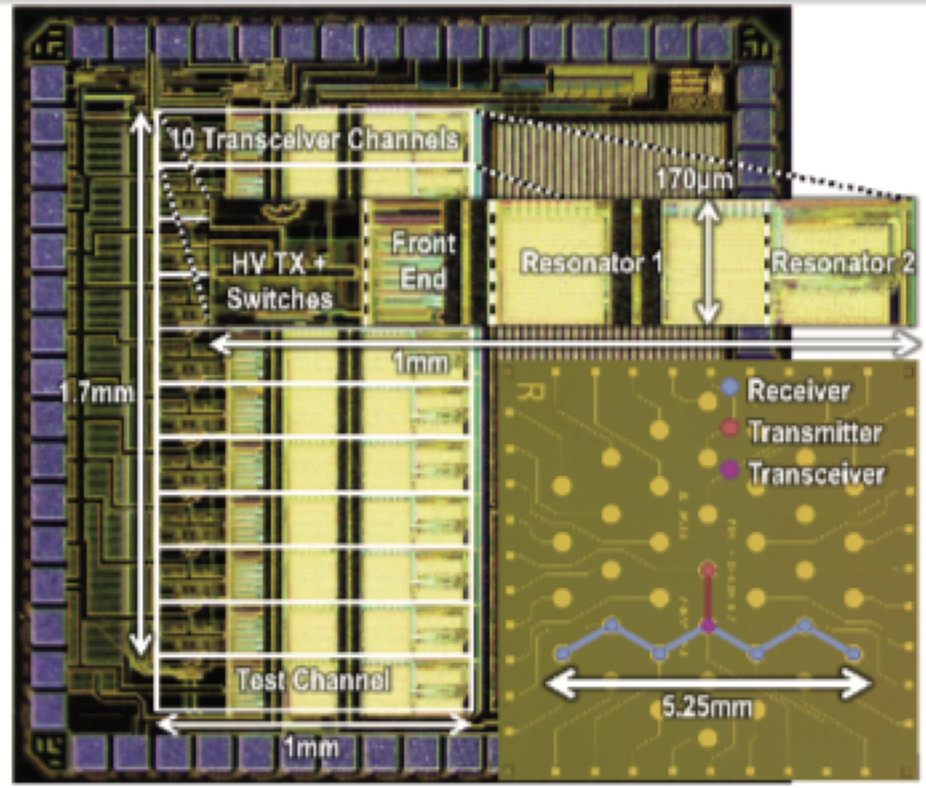
Contact-free Temperature Sensing

DESCRIPTION

The TMP006 and TMP006B are the first in a series of temperature sensors that measure the temperature of an object without the need to make contact with the object. This sensor uses a thermopile to absorb the infrared energy emitted from the object being measured and uses the corresponding change in thermopile voltage to determine the object temperature.

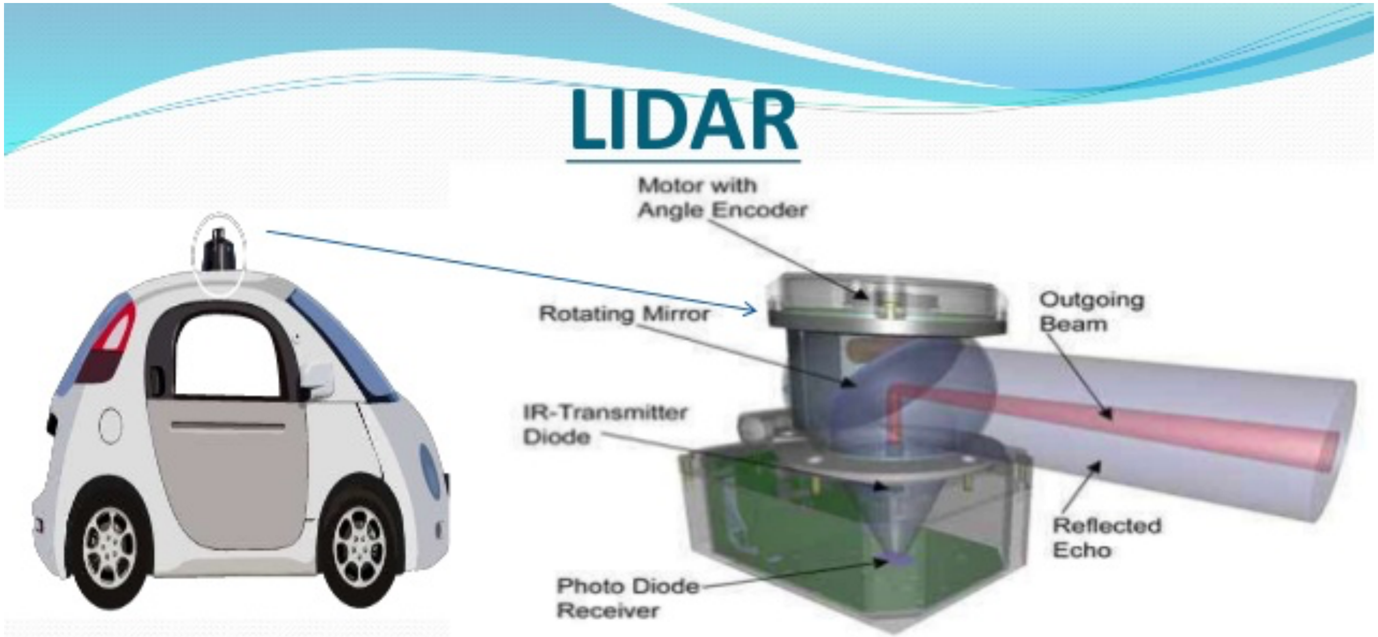
Infrared sensor voltage range is specified from –40°C to +125°C to enable use in a wide range of applications. Low power consumption along with low operating voltage makes the device suitable for battery-powered applications. The low package height of the chip-scale format enables standard high-volume assembly methods, and can be useful where limited spacing to the object being measured is available.

Ultrasound Ranging



Now: Chirp

Time-of-Flight Distance



The heart of Google's self driving car is the rotating roof top camera, Lidar, which is a laser range finder. With its array of 64 laser beams, this camera creates 3D images of objects helping the car see hazards along the way. This device calculates how far an object is from the moving vehicle based on the time it takes for the laser beams to hit the object and come back. These high intensity lasers can calculate distance and create images for objects in an impressive 200m range.

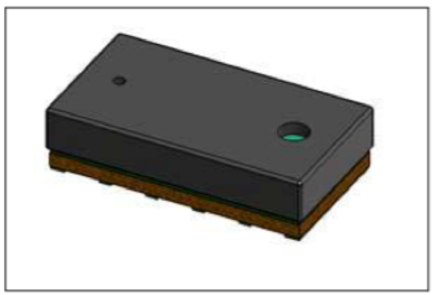
VL53L0X Laser Distance Sensor (Lidar)

VL53L0X

life.augmented

World smallest Time-of-Flight ranging and gesture detection sensor

Datasheet - production data



Features

- Fully integrated miniature module
  - 940nm Laser VCSEL
  - VCSEL driver
  - Ranging sensor with advanced embedded micro controller
  - 4.4 x 2.4 x 1.0mm
- Fast, accurate distance ranging
  - Measures absolute range up to 2m

Applications

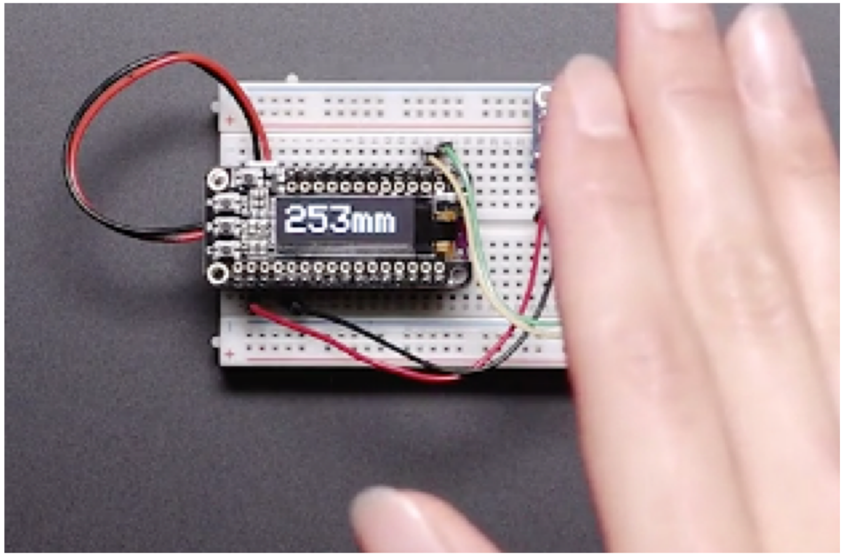
- User detection for Personal Computers/ Laptops/Tablets and IoT (Energy saving).
- Robotics (obstacle detection).
- White goods (hand detection in automatic faucets, soap dispensers etc...)
- 1D gesture recognition.
- Laser assisted Auto-Focus. Enhances and speeds-up camera AF system performance, especially in difficult scenes (low light levels, low contrast) or fast moving video mode.

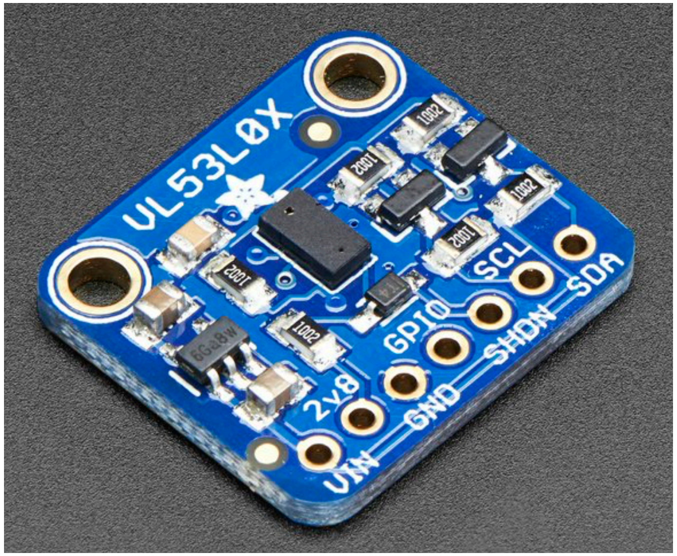
Description

The VL53L0X is a new generation Time-of-Flight (ToF) laser-ranging module housed in the smallest package on the market today, providing accurate distance measurement whatever the target reflectances unlike conventional

Breakout Board

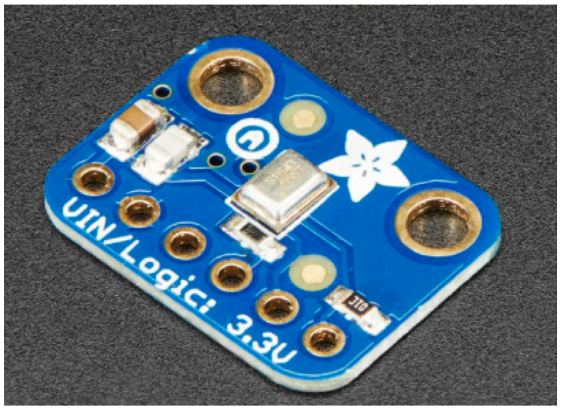
- https://www.adafruit.com/product/3317





Sound

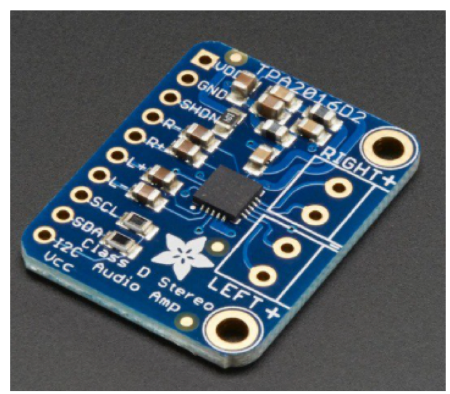
- Microphones



I2**S** output
(digital)

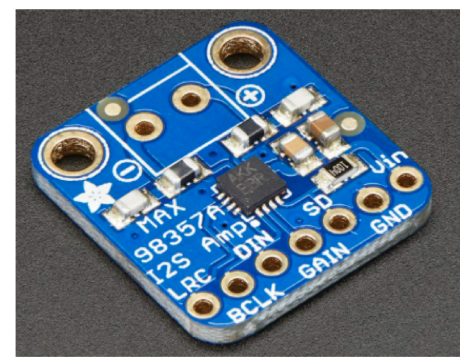
analog output
(ADC)

- Amplifiers, speakers



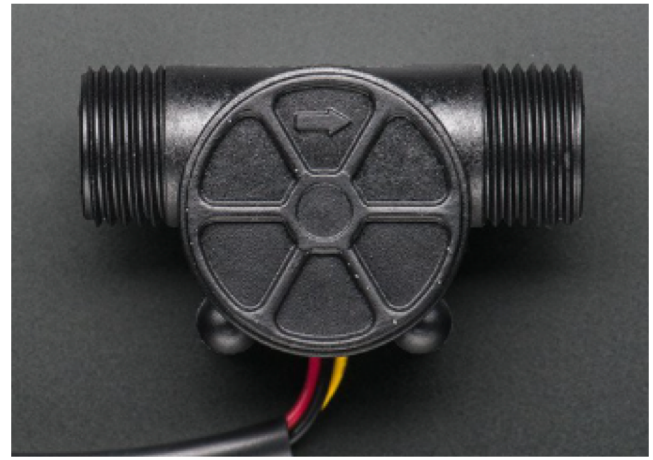
analog input (DAC)

I2**S** input
(digital)

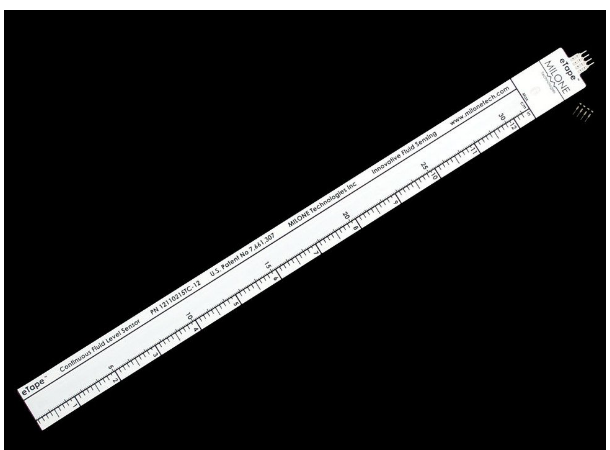


Liquids … Flow, valves, level

Solenoid valve …
use H-bridge (or similar) to drive



Flow sensor, digital pulses out
Pulse counter …



Liquid level … <u>resistive output</u>
Lidar might work, too?

Summary

- Smart sensors
  - "Easy" to use:
    - Complicated stuff is inside
  - Many choices