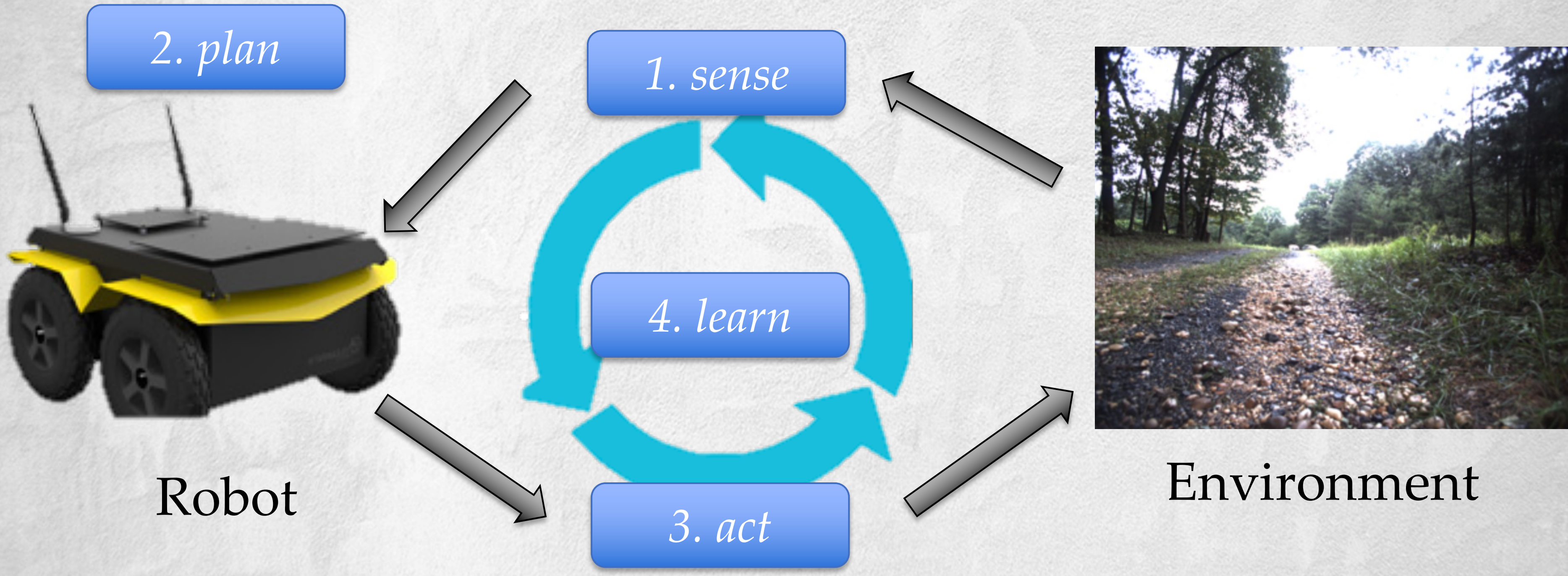
AI Robotics

Sensors & Actuators

Overview

Robot Model

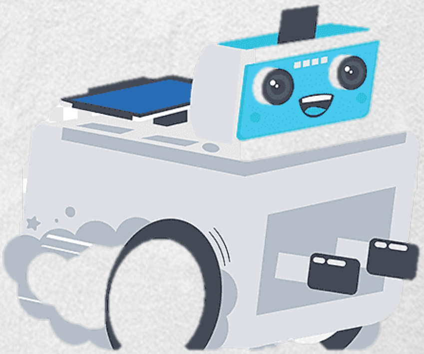


Sensing

- Robot captures information from the surrounding environment
- Helps the robot to move around safely in the environment, i.e. 3D mapping, obstacle detection
- Sensor data can be used for surveillance, monitoring, inspection

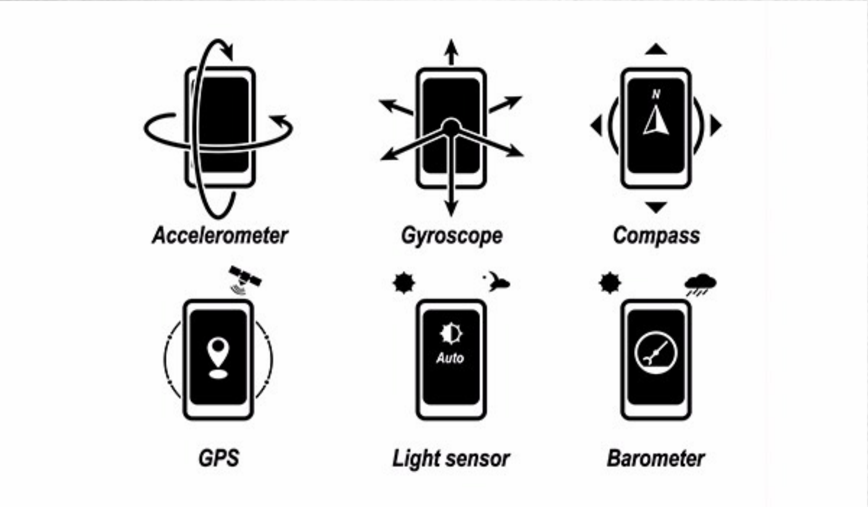
Locomotion

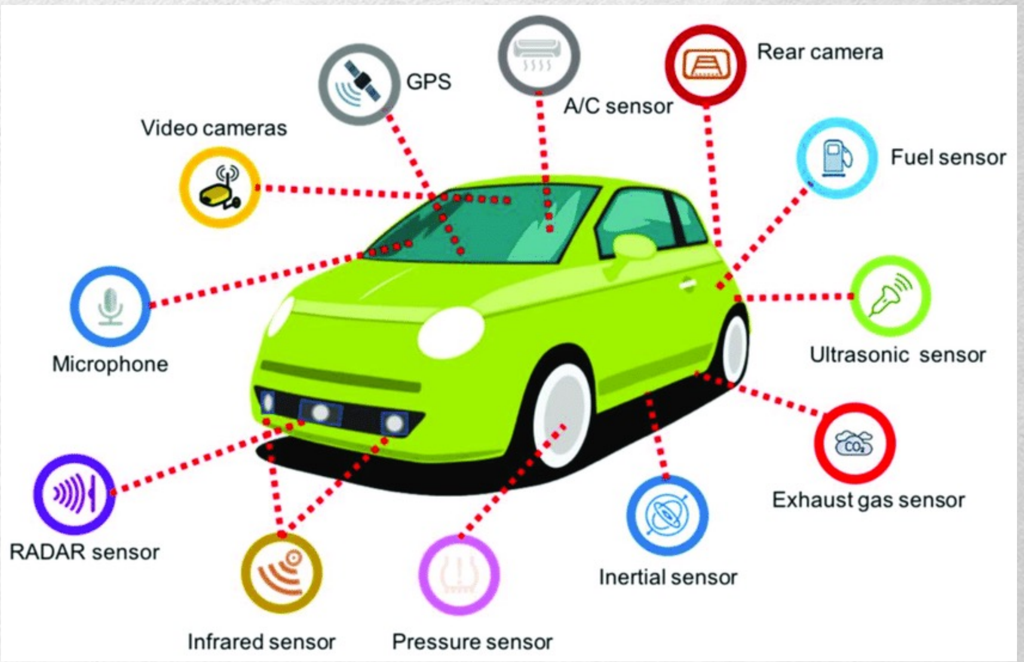
- Robot moves / acts in an environment
- Enables the robot to change its position and orientation
- Depends on type of environment: land, water, air, space, …



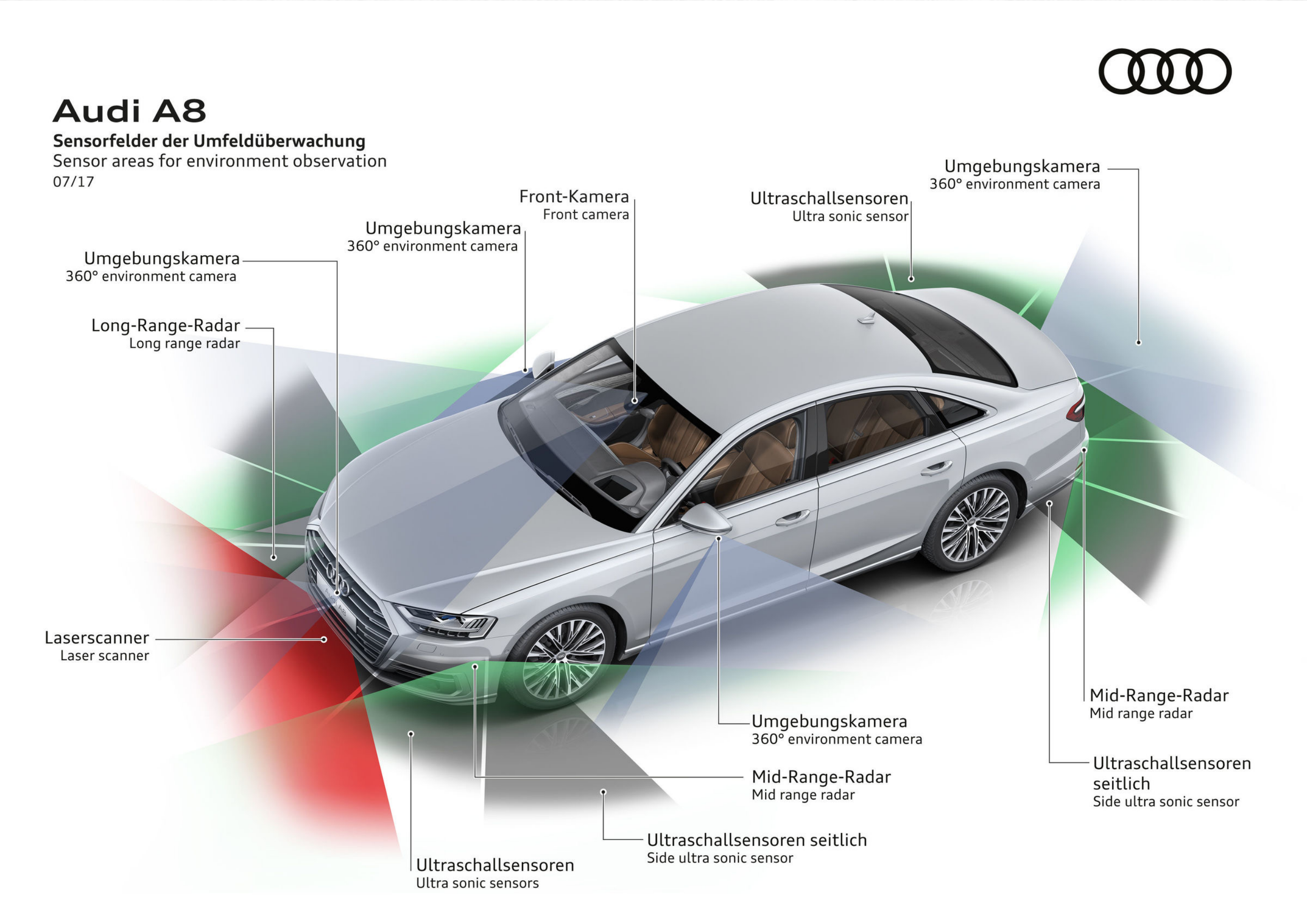
Sensors

Sensors are Ubiquitous

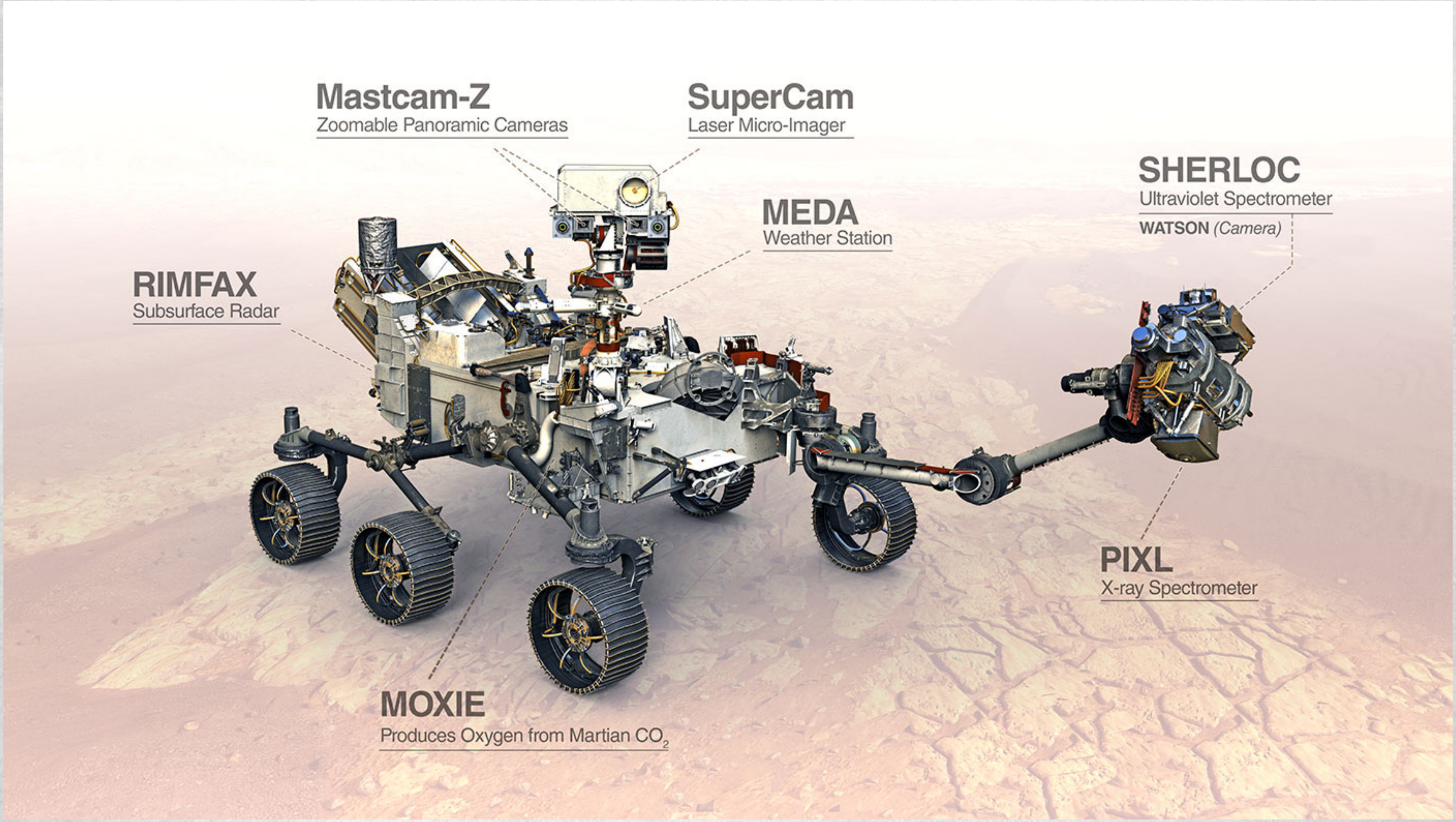




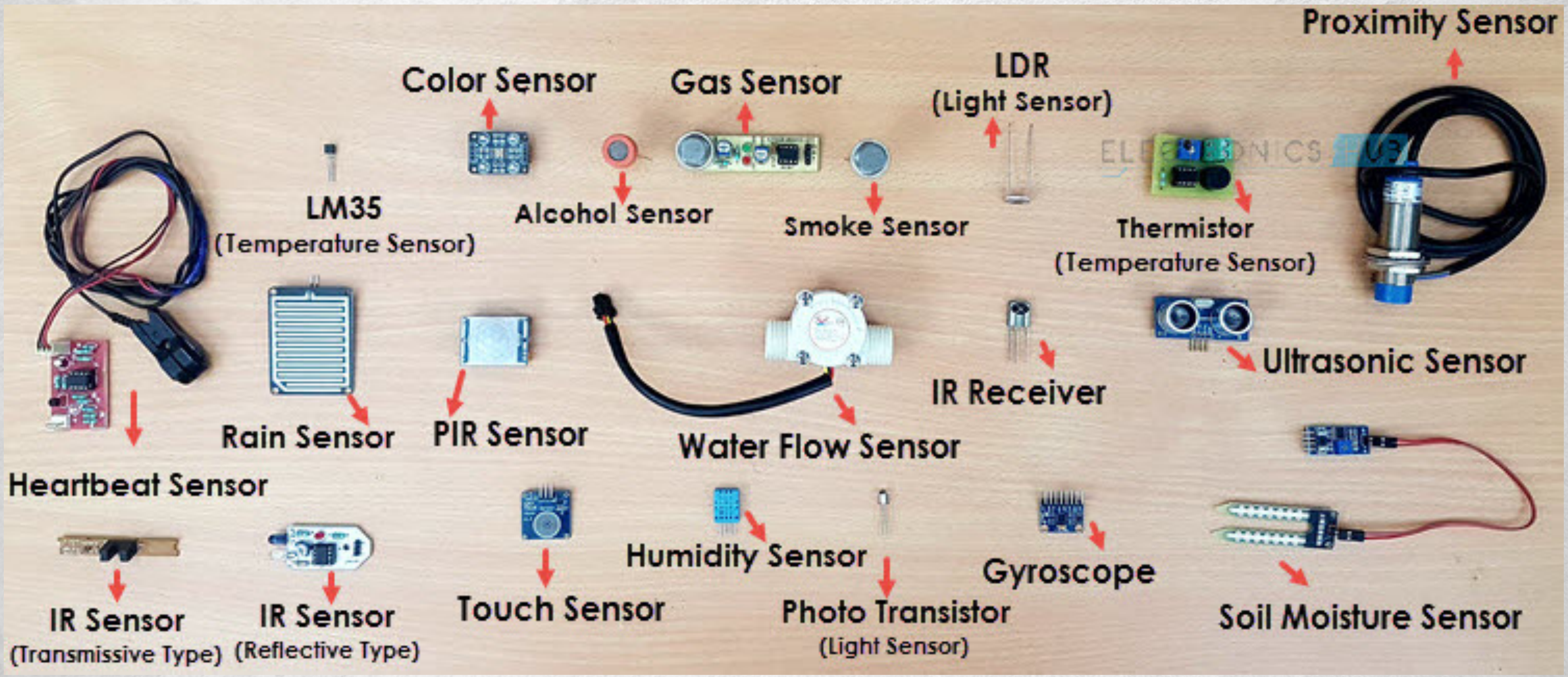
Sensors are Ubiquitous



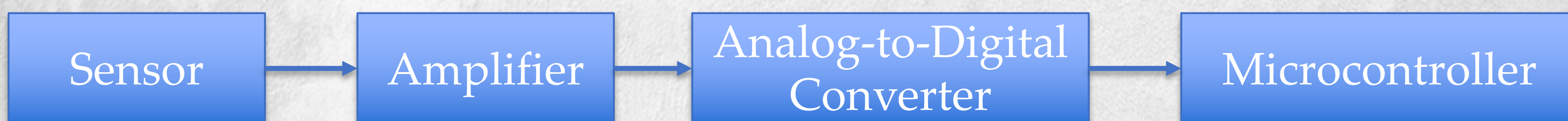
Sensors are Ubiquitous



Other Sensors

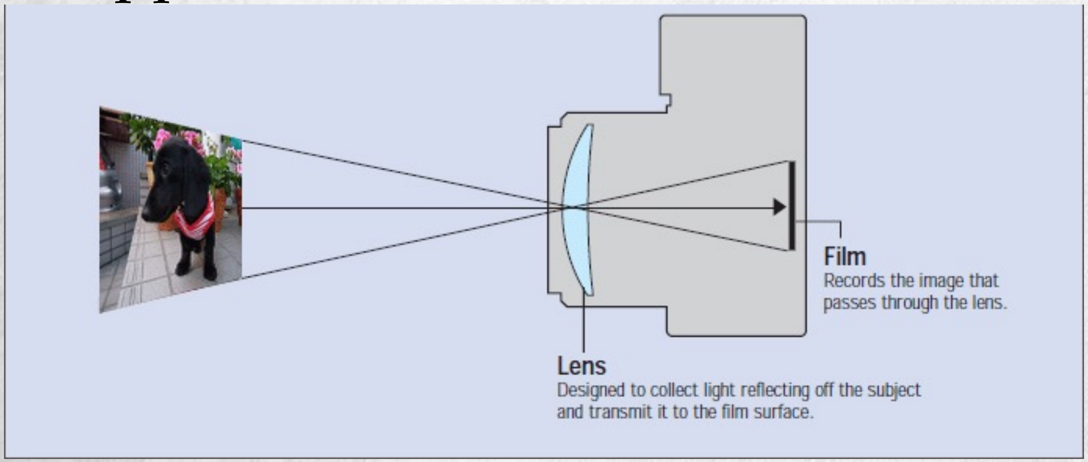


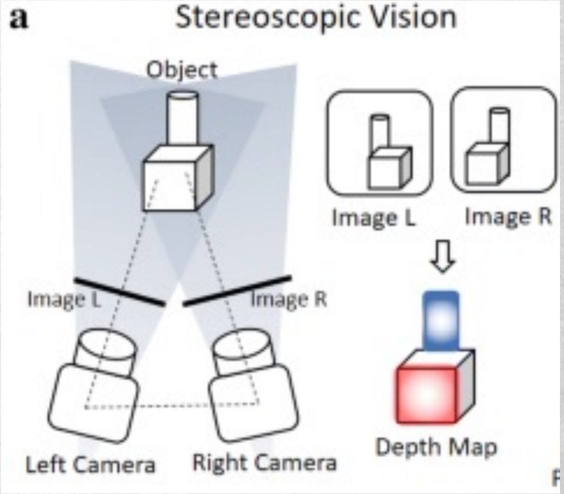
- What do we do with sensors?
  - Measure light intensity, temperature, humidity, pressure, voltage…
- What does a sensor do?
  - A sensor gives us electrical signals.
  - The battery voltage itself is also an electrical signal.
- Typical flow chart to read sensor values



Camera

- Uses Charge-Coupled Device (CCD) sensors to measure light intensity from the environment
- Typically use computer vision techniques or convolutional neural networks to extract useful information
- Modern localization techniques allow robots to extract trajectories from cameras. This is often used for VR and AR applications

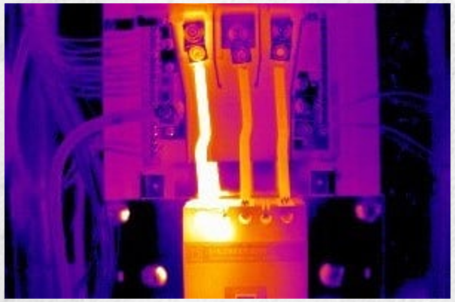
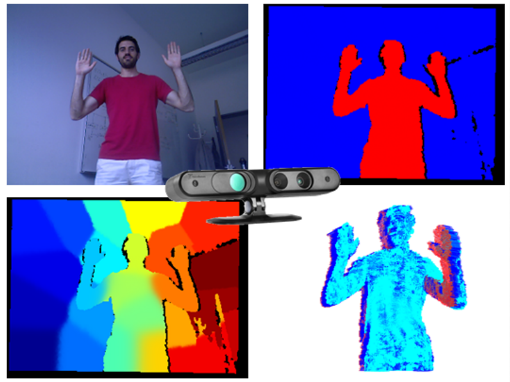




Many different camera setups and types of cameras:

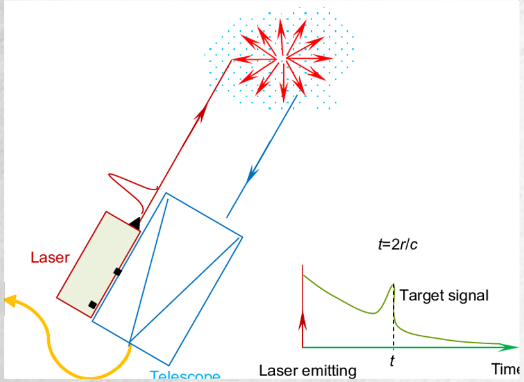
- grayscale (black and white)
- RGB
- RGB-Depth (RGB D)
- stereo cameras
- infrared
- fish eye

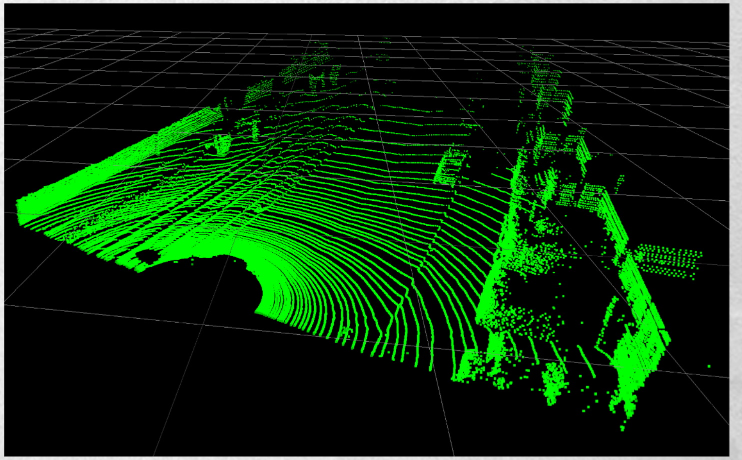


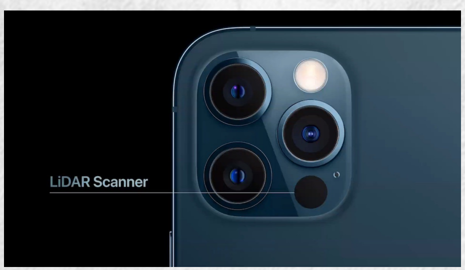

Lidar (Light Detection And Ranging)

- Measures distances to objects using laser beams
- Often these lasers are mounted on a rotating platform. By knowing the angle of the motor, we can calculate the 3D point where that laser hit. These sensors, such as the Velodyne or Ouster pucks can capture hundreds of thousands of points a second.
- Useful for detecting obstacles.



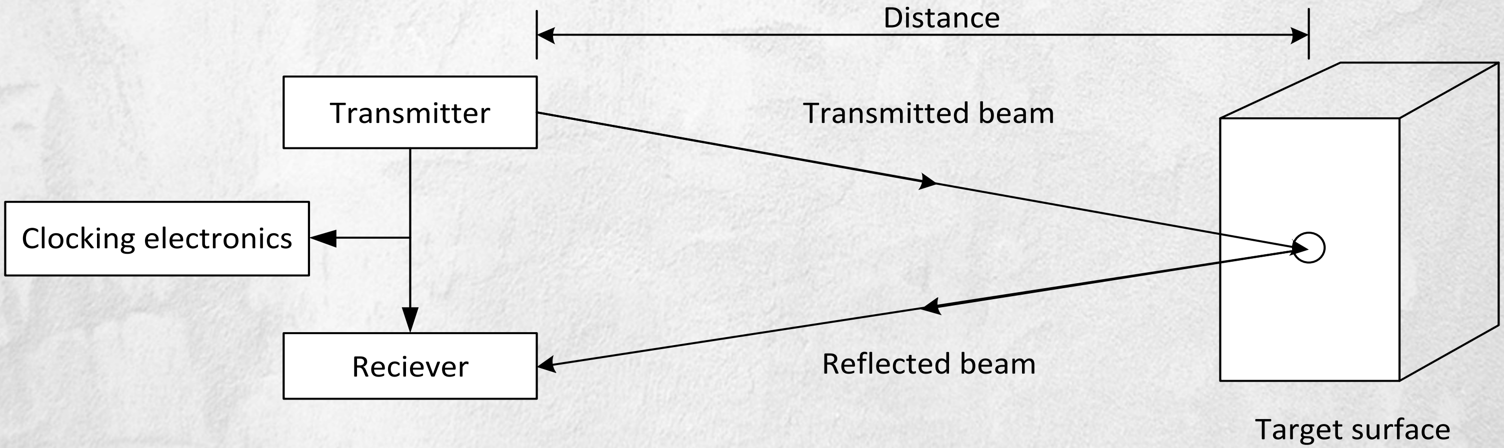


Light Detection and Ranging (LiDAR)



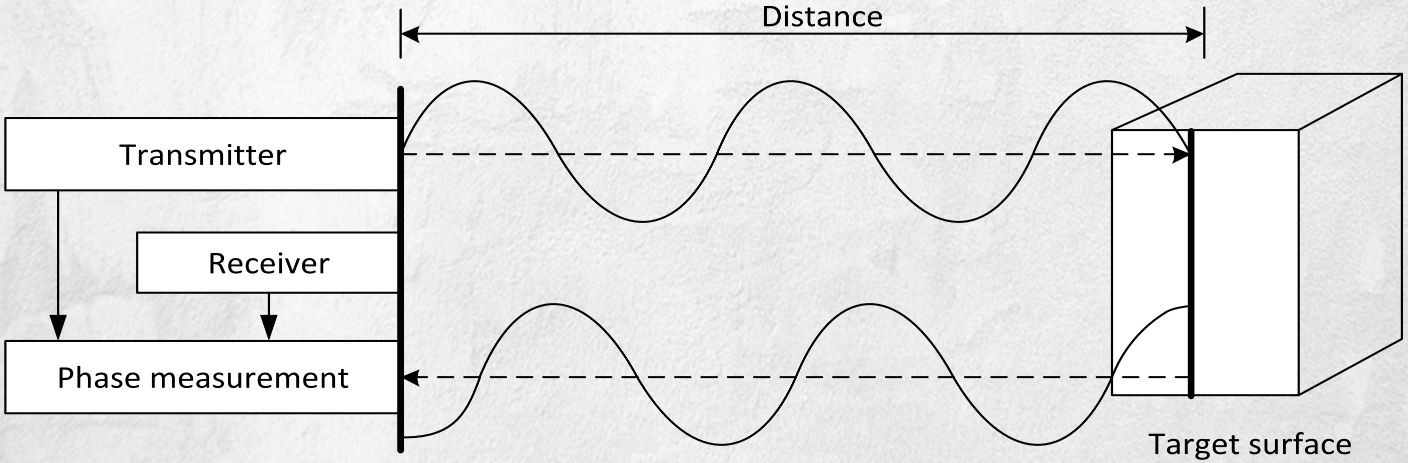
LiDAR Technology – working principles

- Time-of-flight (TOF) based method
  - measure time taken for a laser pulse to travel to target and come back to determine distance

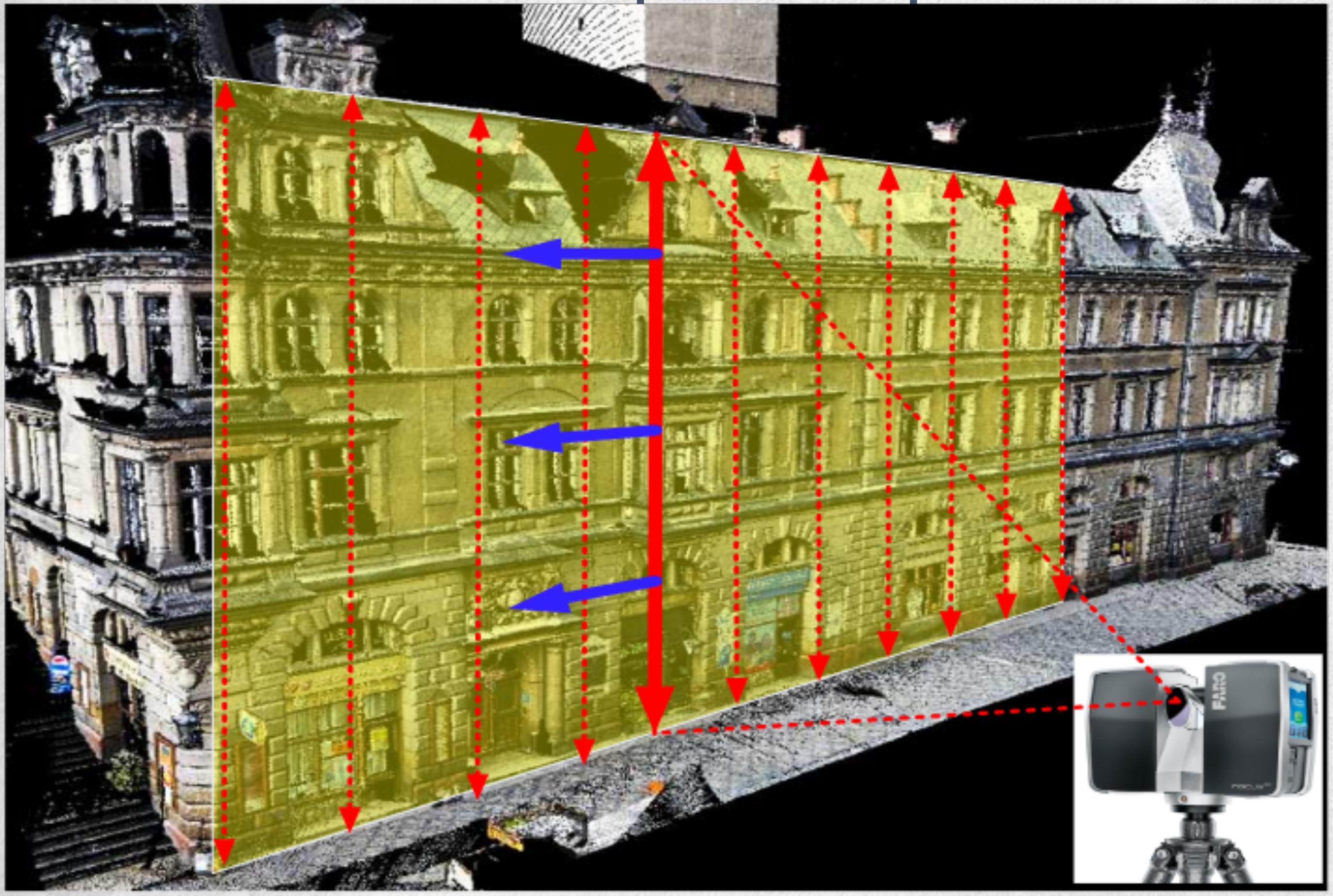


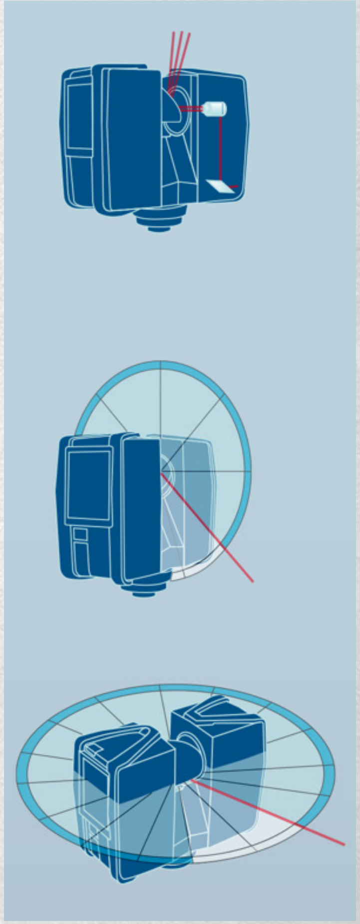
LiDAR Technology – working principles

- Phase-based method
  - measure change in phase of multiple sinusoidal laser pulses to determine time and distance



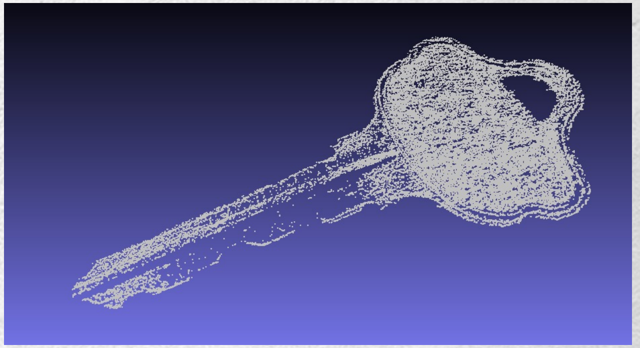
LiDAR Scanning – working principles

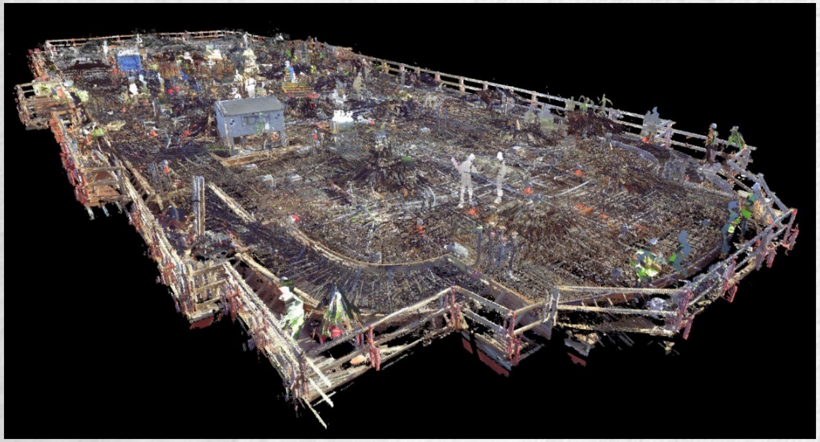




LiDAR scanning– point cloud

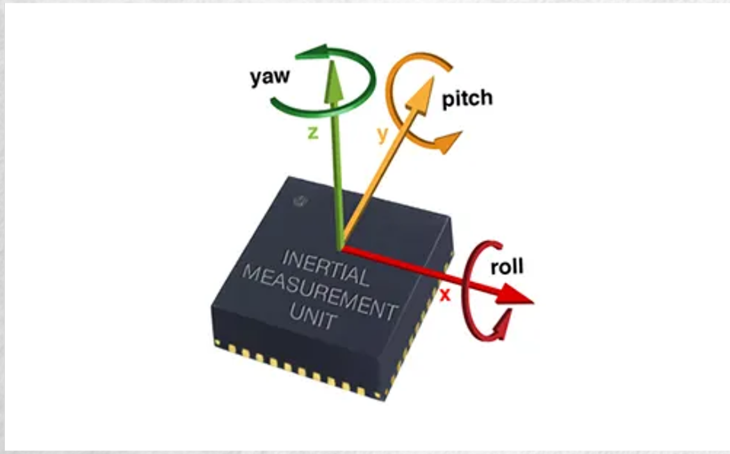
- Point cloud
  - product of a laser scanner
  - a set of points (millions)
  - point info: X, Y, Z, (R, G, B)
  - formats: fls, pts, xyz, las, txt…

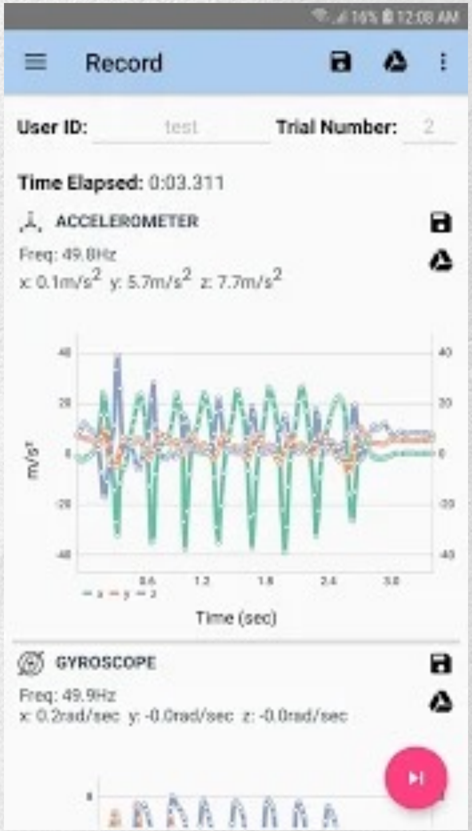




Inertial Measurement Unit (IMU)

- Consists of accelerometer, gyroscope, and magnetometer
- Accelerometer measures linear acceleration (m/s^2)
- Gyroscope measures angular velocity
- Magnetometer measures magnetic field

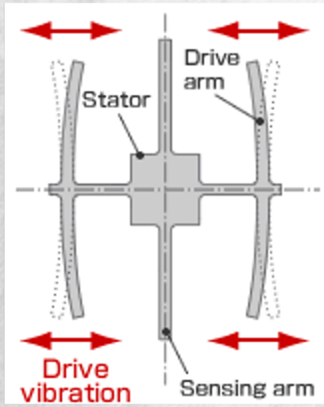


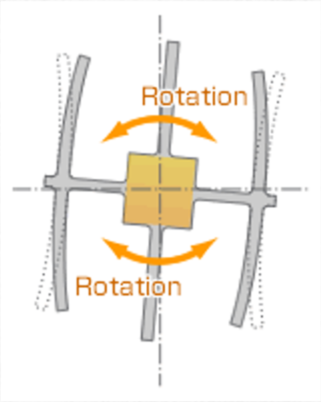


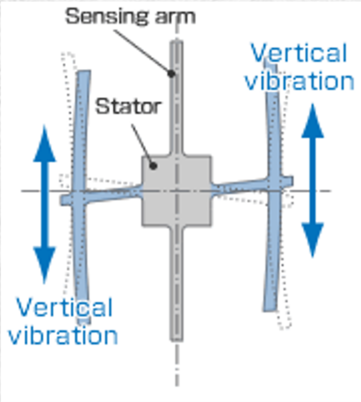
IMU: 3 sensors in 1

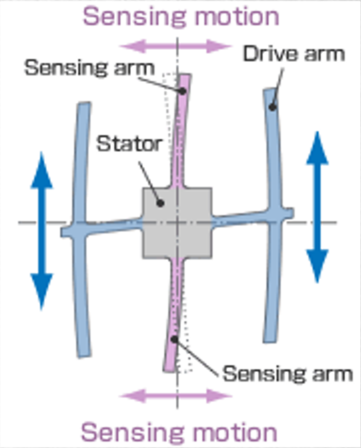
Gyroscope (usually 3, one for each axis of rotation)

- Measures angular velocities (rotation rate)
- Integrating angular velocities can give you relative orientation, but will be susceptible to drift





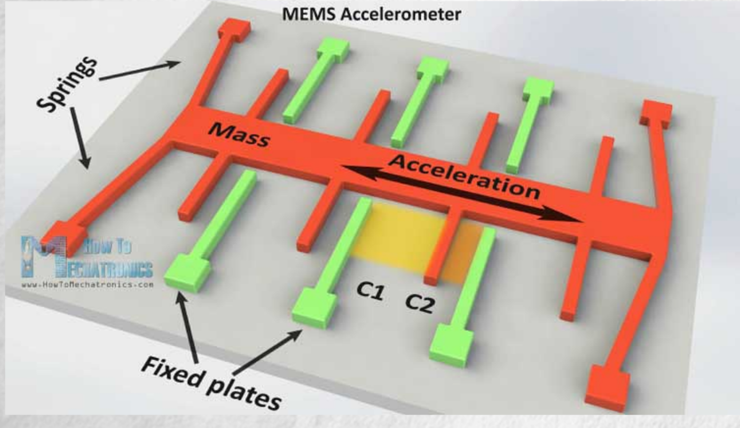


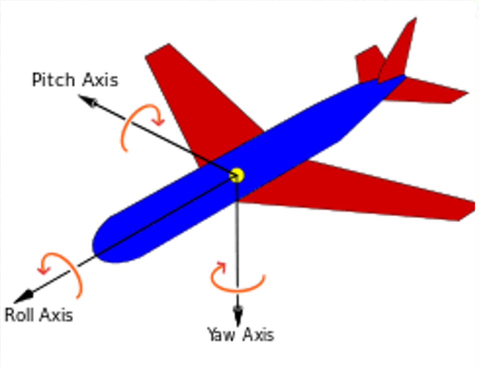


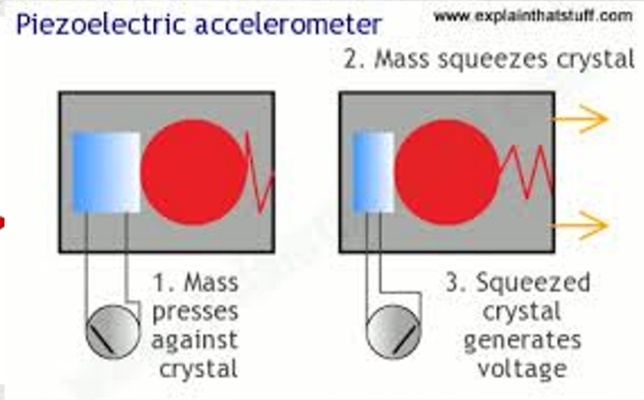
IMU: 3 sensors in 1

Accelerometer (usually 3, one for each axis x, y, & z)

- Measures linear accelerations
- Can be integrated twice to get relative position (sensitive to noise)
- Can use gravity vector to calculate absolute roll and pitch



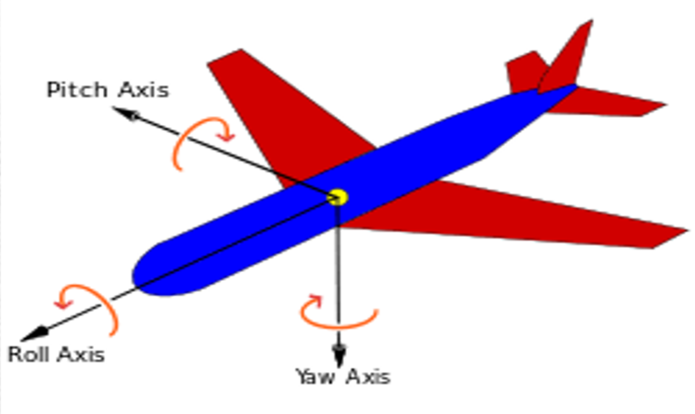




IMU: 3 sensors in 1

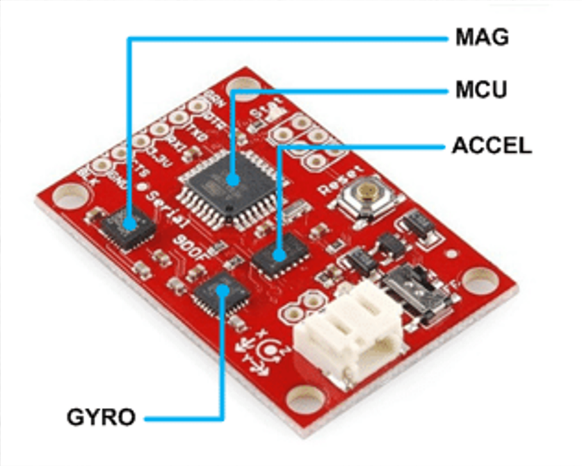
Magnetometer

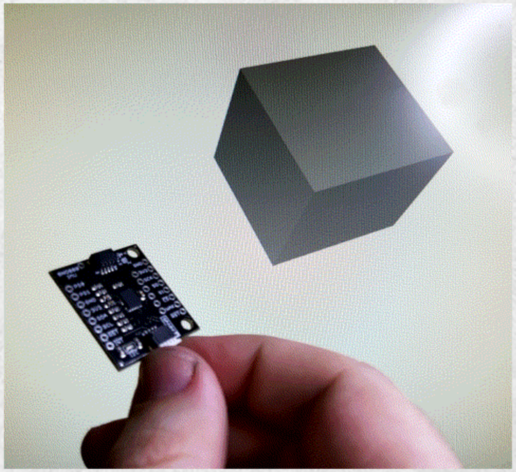
- Measures magnetic field to get heading
- Absolute yaw measurement
- Susceptible to stray magnetic fields (like from motors or steel pillars)



IMU: 3 sensors in 1

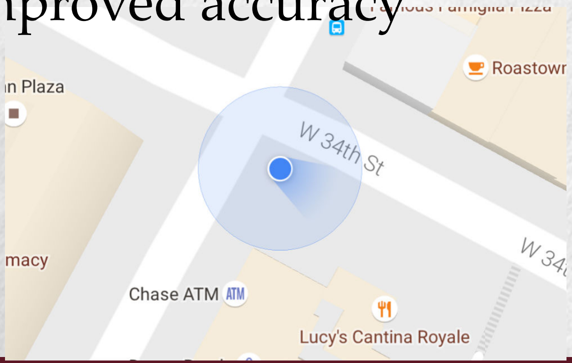
Combining all 3 sensors (gyroscopes, accelerometers, magnetometers), we can generate an accurate orientation estimate and short-term trajectory estimates. Many sensors do this sensor fusion for you and can give you the robot orientation directly as quaternion or Euler angles.

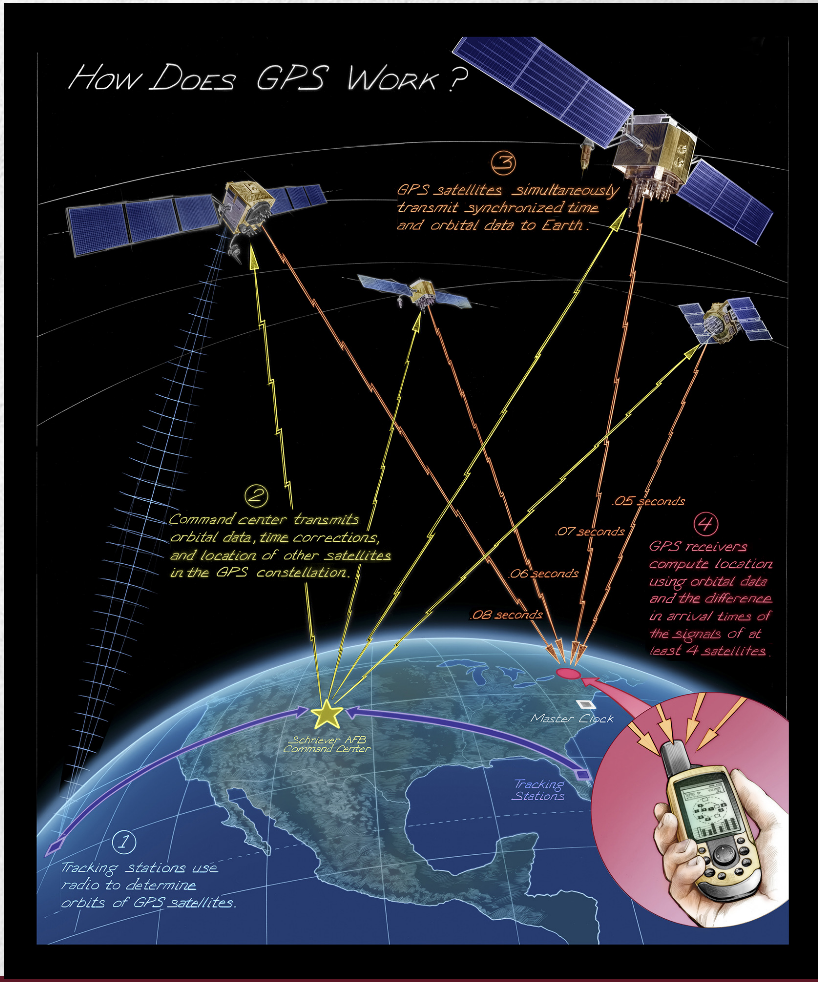




Global Positioning System (GPS)

- GPS receiver calculates its own position and time based on data received from multiple GPS satellites
- Does not work well indoors / underground due to obstructed signals
- Conventional GPS receivers have an accuracy of ~1 m, but multi-band receivers are able to achieve improved accuracy





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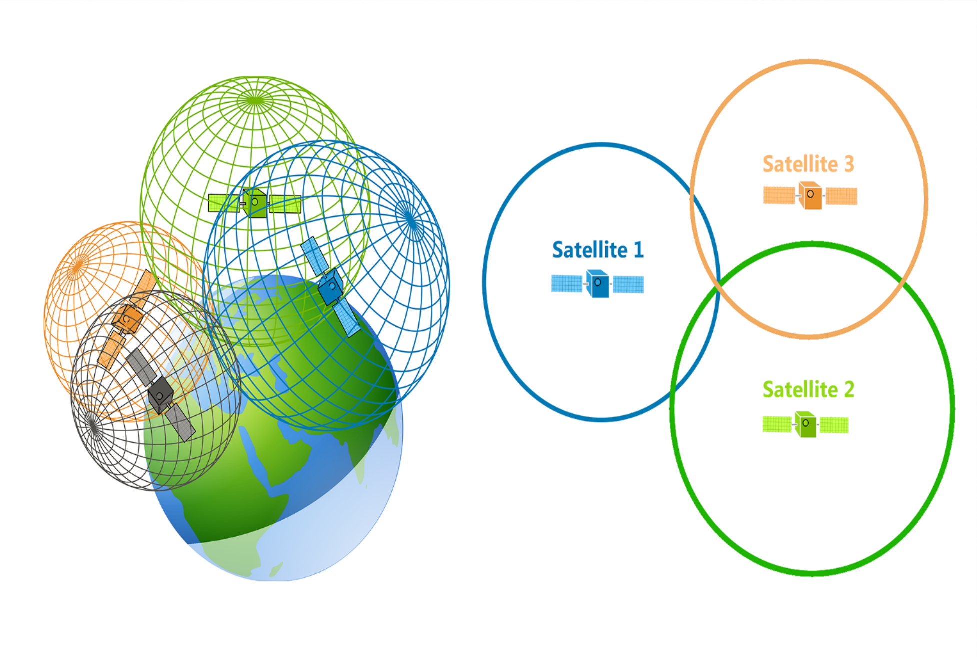
Global Positioning System (GPS)

- Gives absolute global position using longitude and latitude (eg. 33°45'50.0"N 84°23'31.5"W or 33.763892, -84.392071) plus altitude.
- Advantages:
  - Absolute positioning
  - Relatively cheap
- Disadvantages:
  - Infrequent updates
  - 4-50 m accuracy for commercial GPS



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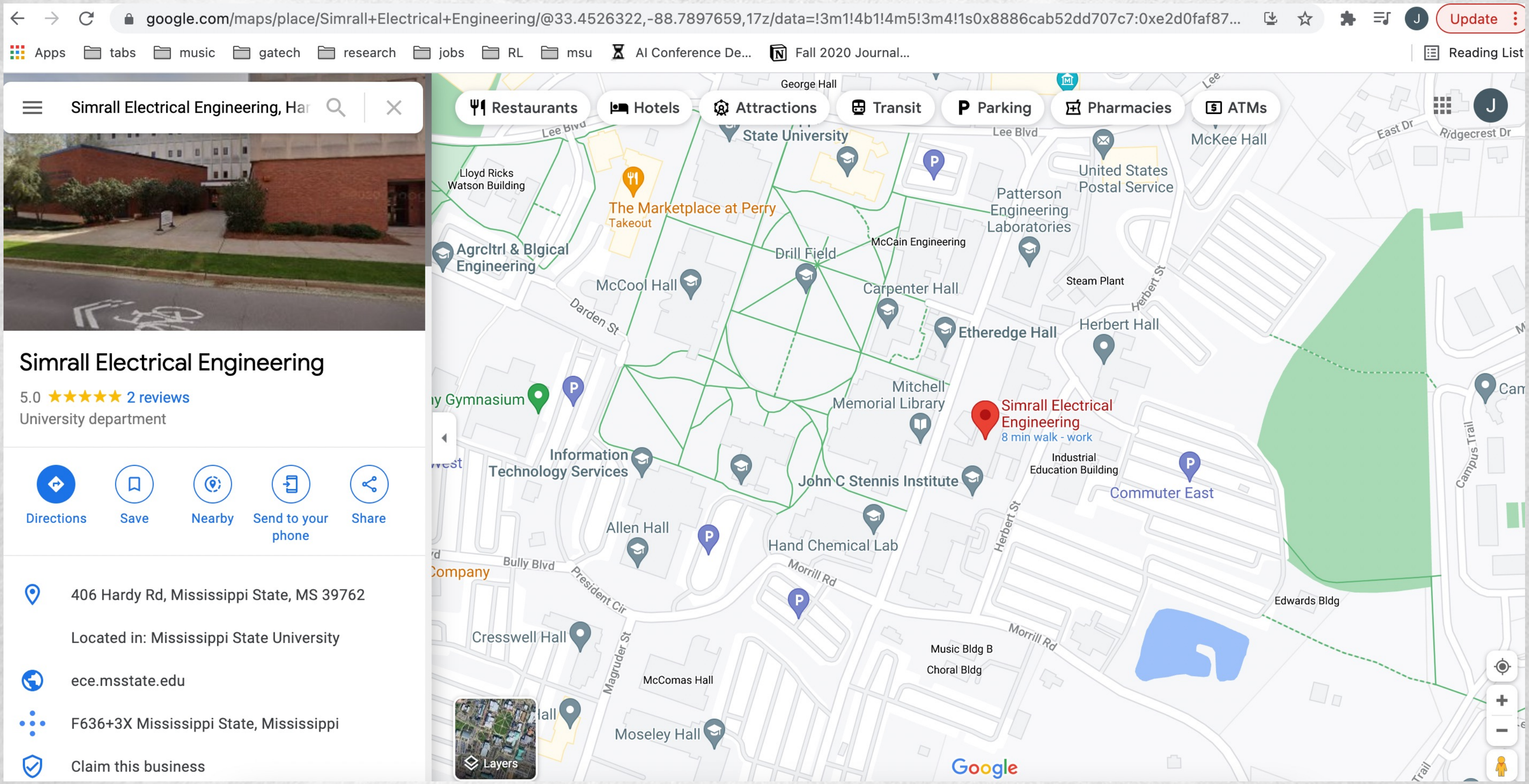
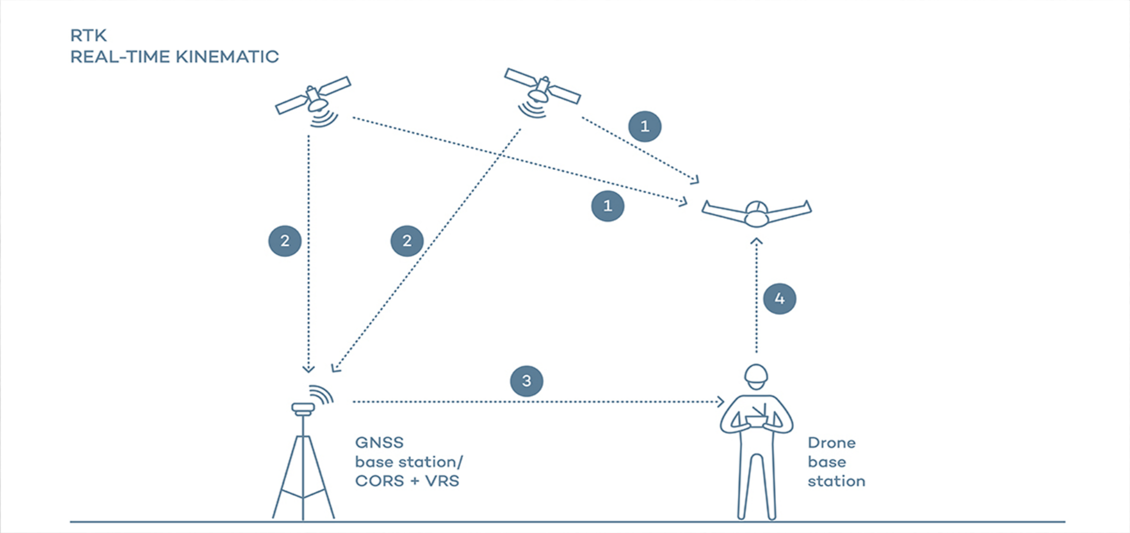


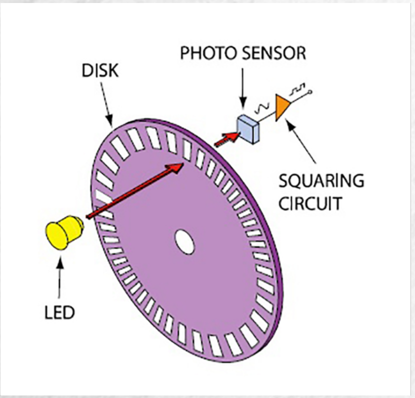
Real-time Kinematic (RTK) positioning

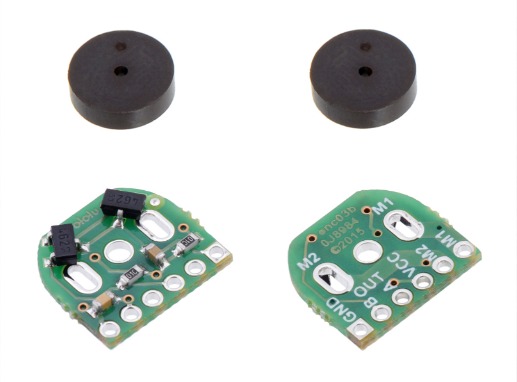
- Uses a stationary reference station or multiple stationary stations that are able to average gps measurements to get the stations precise position.
- The receiver on the robot then measures the phase of the signal from the reference station to get centimeter level accuracy.
- Can provide much higher precision and much more frequent updates



Encoders

- There are many types of encoders, but they all perform the same function with different levels of precision.
- They measure how much a motor or shaft has rotated.
- They typically count the number of steps taken, where each step is fraction of a rotation (eg. 1/200th of a rotation or 1.8°)





Actuators

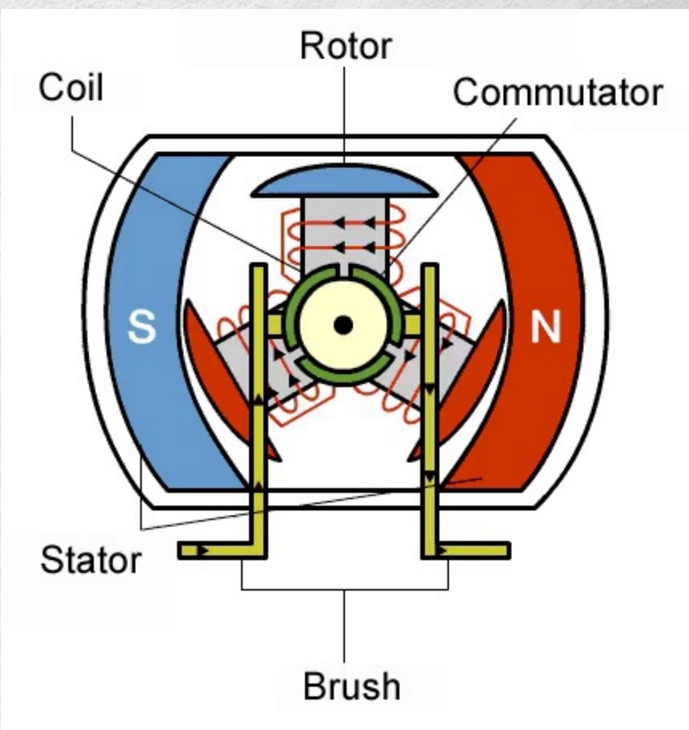
Locomotion

Rotational & Linear Actuators

- Type of actuators by movement
  - Rotational actuator
  - Linear actuator
- Rotational & linear movements are convertible
  - Engine: linear (piston) → rotational (shaft)
  - Vehicle: rotational (wheel) → linear (vehicle)

DC Motor

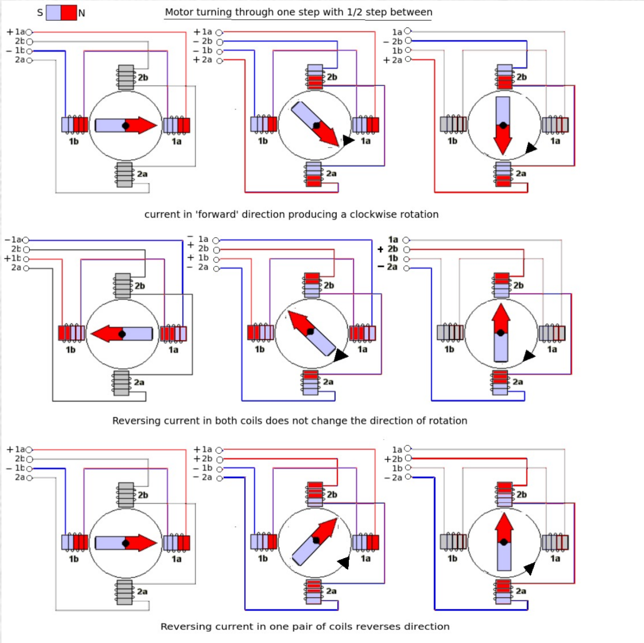
- Direct current runs the motor
  - Current → torque
- Instead of pulse, commutator changes the poles to rotate.
  - No way to know the position/velocity
  - Often used with encoder (sensor)



https://www.seeedstudio.com/blog/2019/04/01/choosing-the-right-motor-for-your-project-dc-vs-stepper-vs-servo-motors/

Stepper Motor

- "Each pulse rotates the shaft through a fixed angle."
  - High torque @ low speed
    - Low torque @ high speed
  - Low energy efficiency
  - No feedback needed
    - Num pulses = rotated angle
    - If out of sync, loses control
      - No rapid acceleration/deceleration



References

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