# CSC 445 - Intro to Intelligent Robotics, Spring 2018

Sensors

# Sensors

- An autonomous system must acquire knowledge about its environment.
- Robotics applications do this by taking measurements from various sensors and the extracting meaningful information from those measurements.
- A *sensor* is a device that detects or measures a physical property and records, indicates, or otherwise responds to it.

# Classifying Sensors

- Proprioceptive vs Exteroceptive
  - A proprioceptive sensor measures values *internal* to the system.
  - An exteroceptive sensor acquires information from the robot's environment.
- Active vs Passive
  - An active sensor emits energy into the environment and measures the environmental reaction.
  - A passive sensor measures ambient environmental energy entering the sensor.

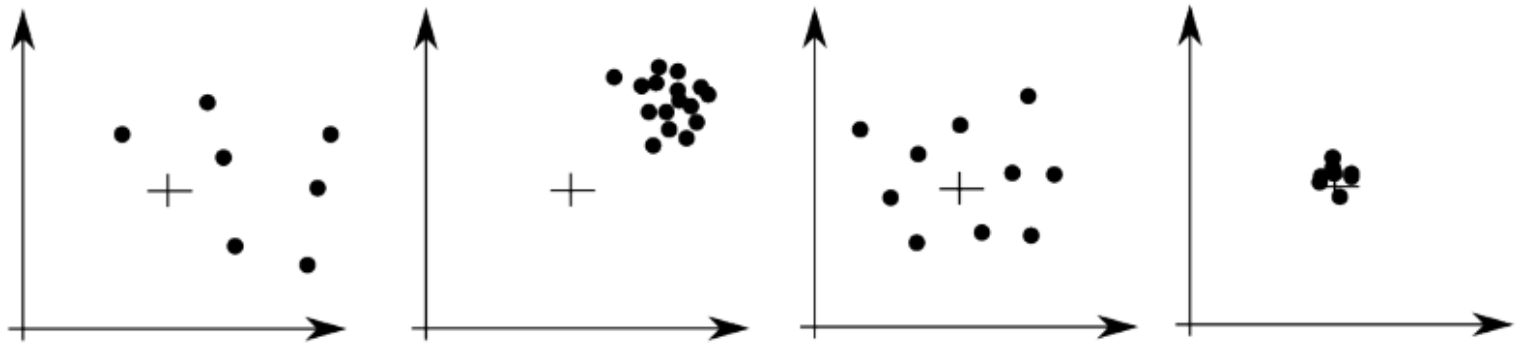
# Sensor Response Ratings

- Dynamic range: measures the spread between the lower and upper limits of the input values to the sensor.
- Resolution: the minimum difference between two values that be detected by a sensor.
- Linearity: a measure governing the behavior of the sensor's output signal to its input signal.
- Bandwidth or frequency: the speed at which a sensor can provide a stream of readings.

# Sensor Performance

- Sensitivity: measure of the degree to which an incremental change to the input signal changes the output signal.
- Cross-sensitivity: sensitivity to environmental parameters that are orthogonal to the target parameters for the sensor.
- Error: the difference between the sensor's output measurements and the true values being measured.
- Accuracy: the degree of conformity between the sensor's measurement and the true value.
- Precision: relates to reproducibility of the results.

# Accuracy and Precision



From left to right, the cross corresponds to the true value:

- neither precise nor accurate
- precise but not accurate
- accurate but not precise
- accurate and precise

# Characterizing Sensor Error

- Systemic errors: caused by factors that can be modeled.
- Random errors: cannot be modeled deterministically.
- Blurring of systemic and random errors:

# Sensor calibration

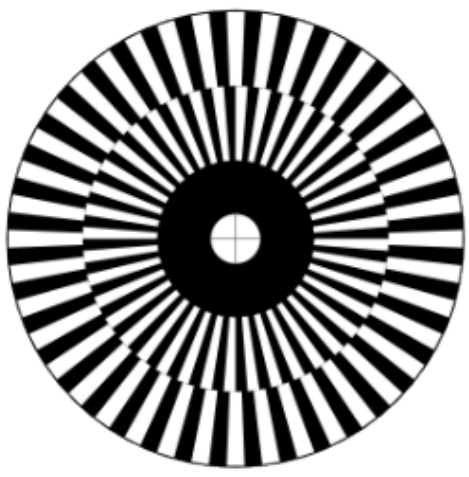
- Intrinsic calibration
- Extrinsic calibration

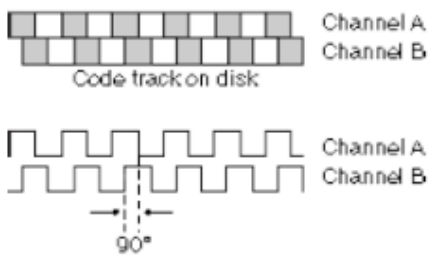
# Common Sensors

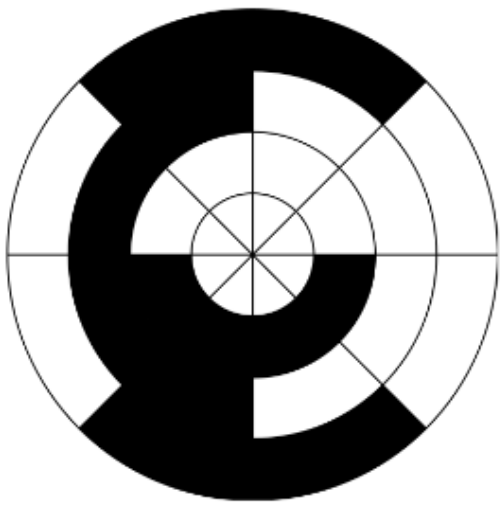
- Optical encoders
- Heading sensors
  - Compass
  - Gyroscopes
  - Accelerometers
- Beacons
  - Global Positioning System
- Active Ranging
  - Time-of-flight
  - Triangulation
- Vision

# Optical Encoders

- Optical encoders are proprioceptive sensors that measure the angular speed or position of a wheel or steering mechanism.
- A quadrature encoder relies on a pattern that rotates with the shaft and an optical sensor that can register black/white transitions.





# Compass

- A compass is an exteroceptive heading sensor.
- A compass detects the Earth's magnetic field.
- Compasses tend to have cross-sensitivity to ferrous objects in the environment.

# Gyroscope

- A gyroscope is a proprioceptive heading sensor that preserves its orientation with respect to a fixed reference frame.
- Two main types:
  - Mechanical: rely on the inertial properties of a fast spinning rotor.
  - Optical: measure angular speed based on two monochromatic light beams emitted from the same source.
- A rate gyro measures angular speeds instead of absolute orientation.

# Accelerometer

- An accelerometer is a proprioceptive sensor that measures all external forces acting upon it.
- Acceleration measurements include all specific forces (gravitational, centripetal accelerations and Coriolis effects) not only accelerations induced by the sensor translation.

# Inertial Measurement Unit (IMU)

- An inertial measurement unit (IMU) is a device that uses gyroscopes and accelerometers to estimate the relative position, velocity, and acceleration of a moving vehicle.
- An IMU estimates the six-degree-of-freedom pose of a vehicle.
- Note: bias in accelerometers/gyros induces errors in position that scale quadractically/cubically with time.

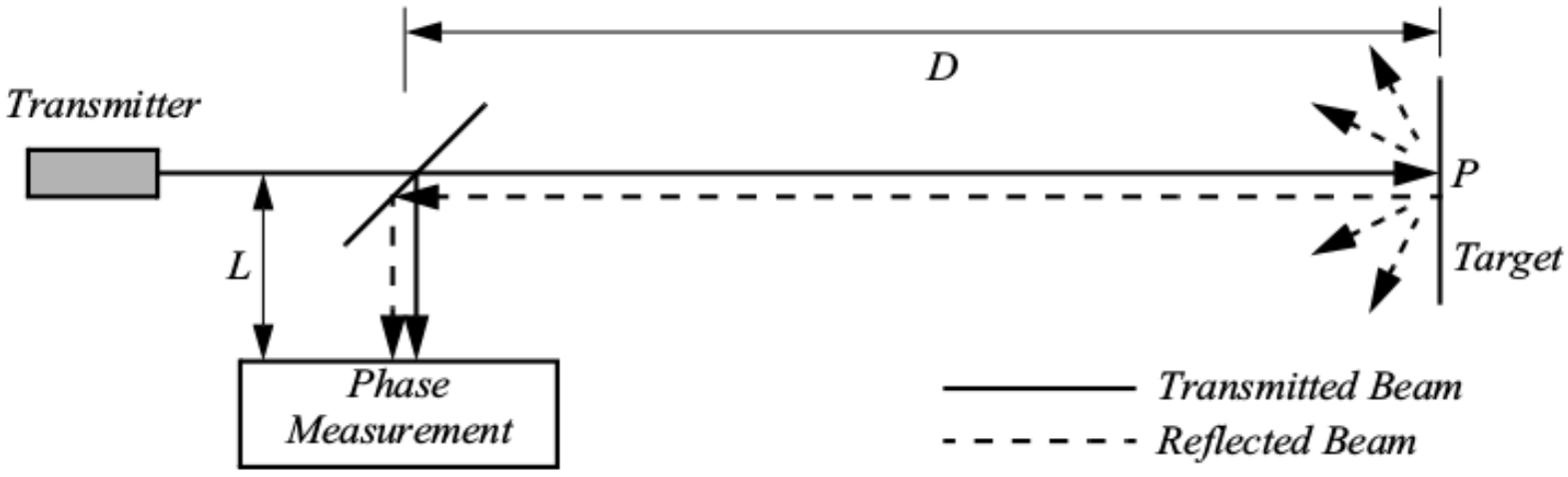
# Global Positioning System (GPS)

- The global positioning system is based on satellites that continuously transmit data that indicates its location and current time.
- A GPS receiver is a passive, exteroceptive sensor that measures the relative distance to the satellites based on arrival time measurements.
- A GPS receiver can infer its position by combining the information from four satellites: three for triangulation of position and one to estimate time.

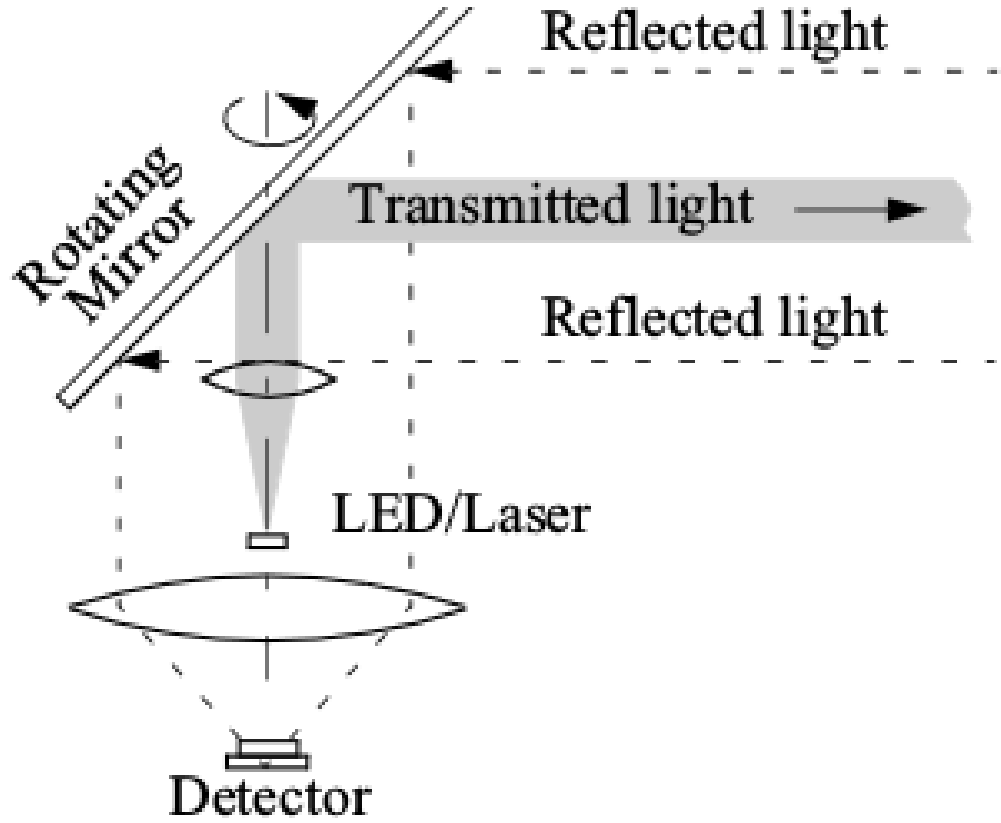
# Active Ranging

- Active ranging sensors are active, exteroceptive sensors
- The output is easily interpretted – direct distance measurements
- Categories of active ranging
  - Time of flight: based on $d = c \cdot t$ where $d$ is distance traveled, $c$ is the speed of wave propogation, and $t$ is the time of flight.
    - ultrasonic
    - laser range finder
    - time of flight camera
  - Geometric
    - optical triangulation
    - structured light

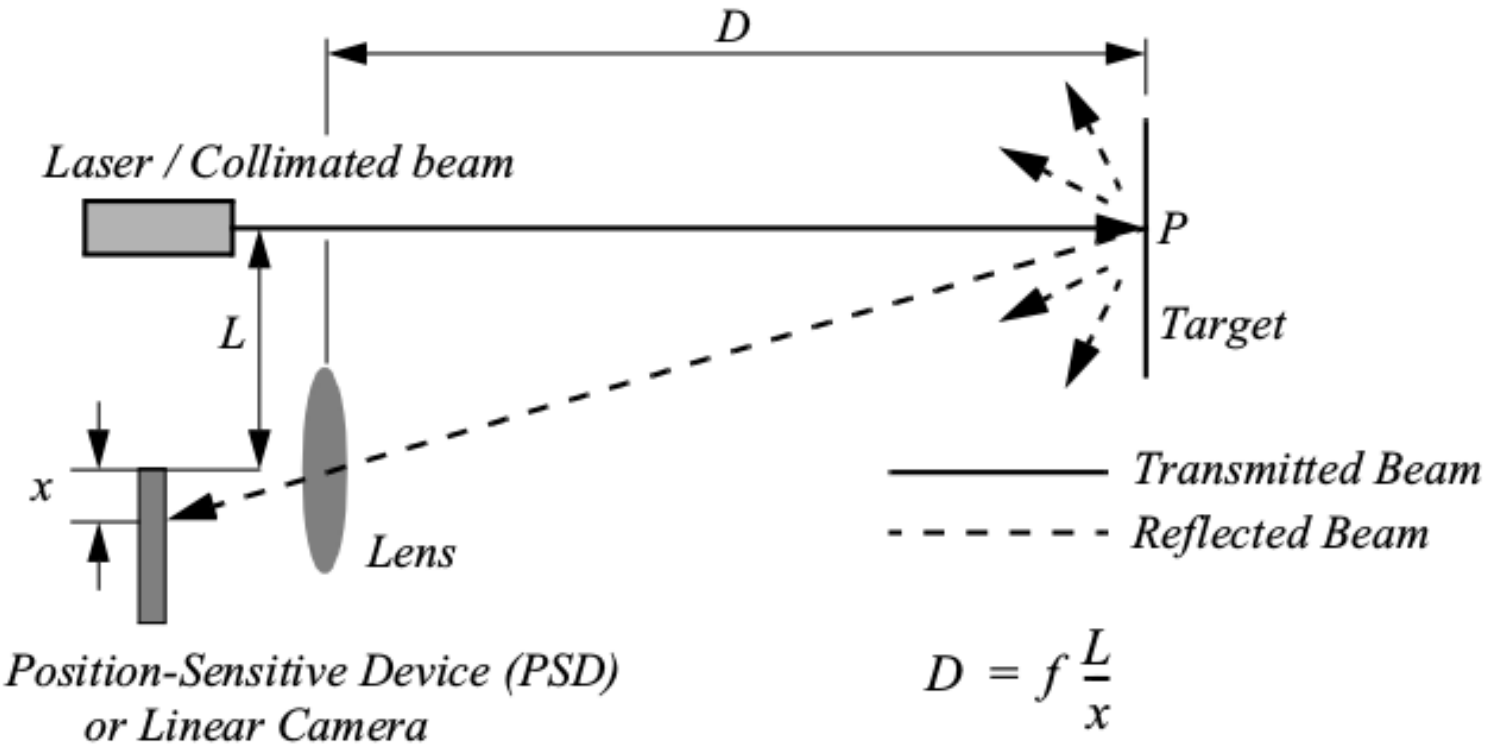
# Time of Flight Laser Range Finder



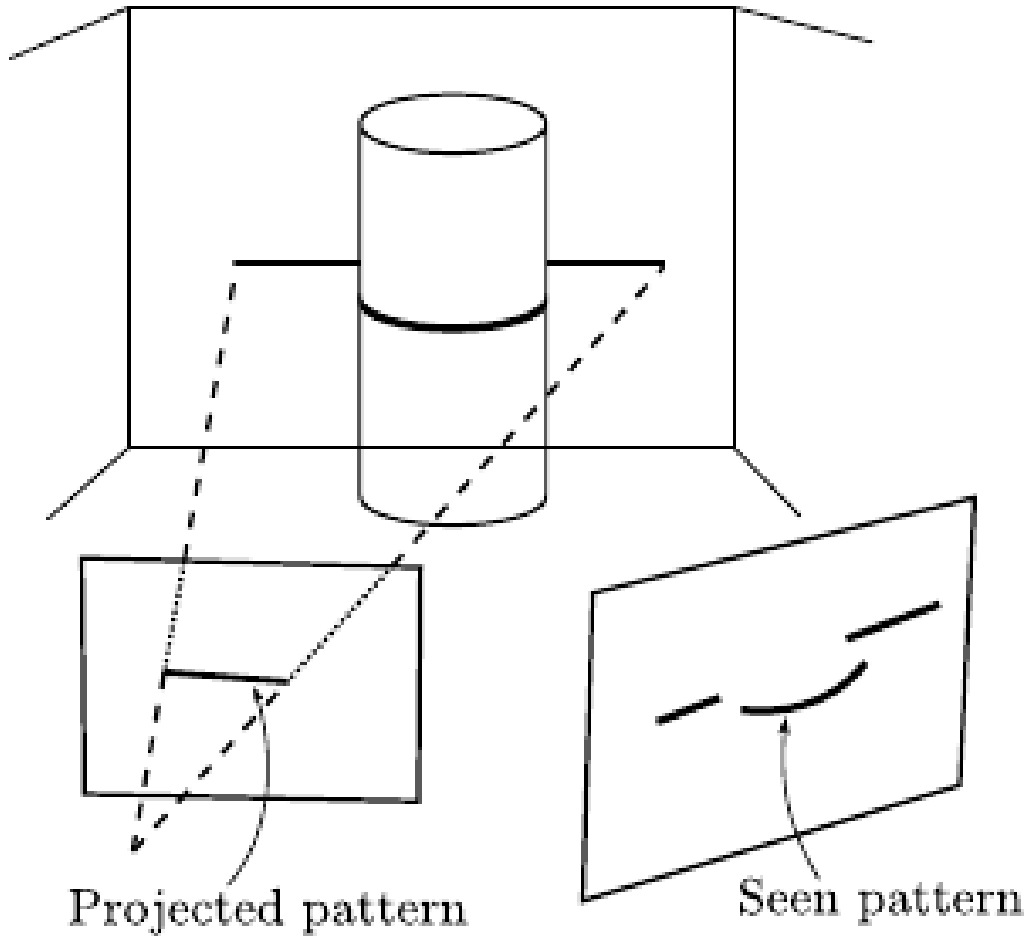
# Rotating Laser Range Finder



# Triangulation

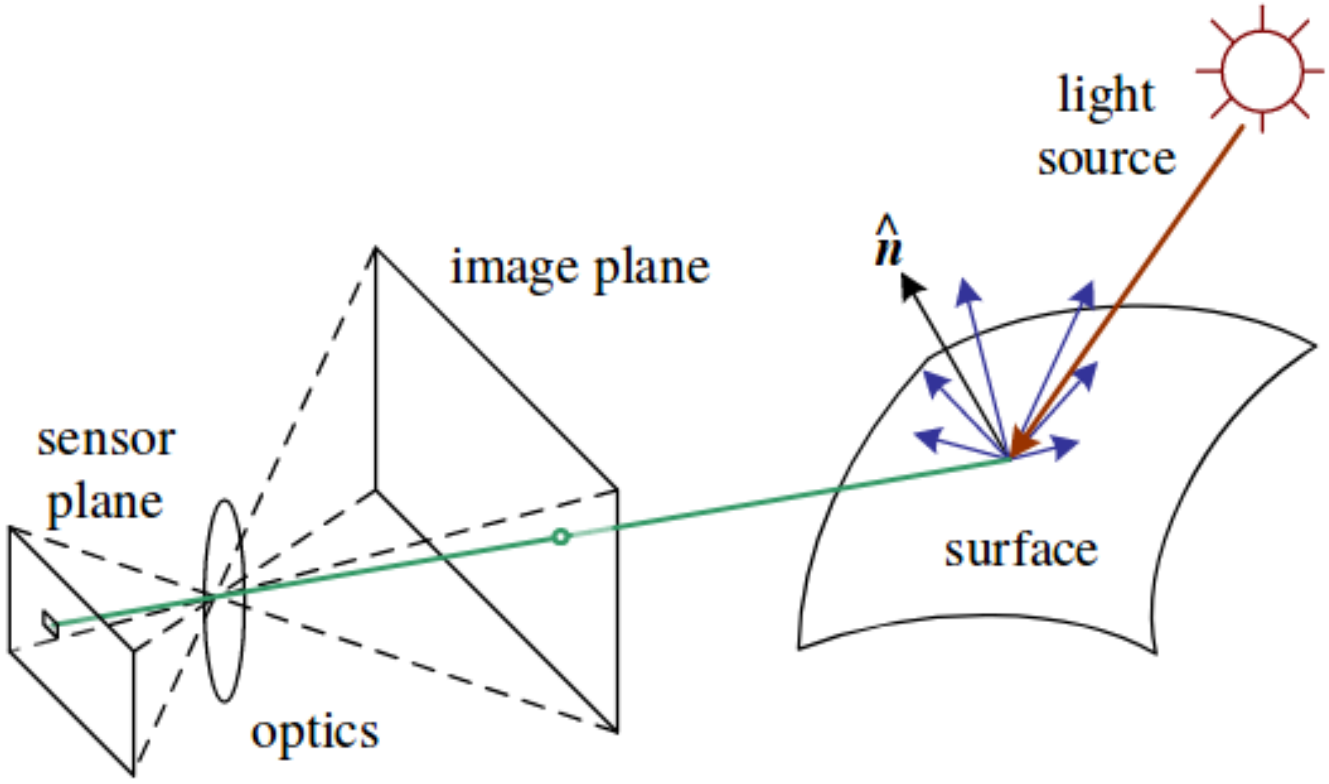


# Structured Light



# Vision

- A camera is a passive sensor that measures light reflecting off of surfaces in the world.



# Digital Cameras

- Digital cameras measure light by integrating the amount of photons picked up by an active sensing area for the duration of the exposure.
- The shutter speed (exposure time) directly controls the amount of light that reaches the sensor.
- The sensing area can only detect light; detecting color information requires additional considerations.

# Bayer Filter

| | | | |
|---|---|---|---|
| G | R | G | R |
| B | G | B | G |
| G | R | G | R |
| B | G | B | G |

| | | | |
|---|---|---|---|
| rGb | Rgb | rGb | Rgb |
| rgB | rGb | rgB | rGb |
| rGb | Rgb | rGb | Rgb |
| rgB | rGb | rgB | rGb |

- (Left) The Bayer filter is a color filter array layout.
- (Right) The color value for a pixel is estimated by guessing the unknown values, shown in lower case.
- The process of determining the color value for a pixel is called demosaicing.