Intelligent Robotics
Sensors

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The Perception Problem

- **Do we need perception?**
  - Complexity
  - Uncertainty
  - Dynamic World
  - Detection/Correction of errors
- **A robot must perceive its physical environment to get information about itselt and its surroundings**

The Perception Problem

- **What does a robot needs to sense**
  - Depends on what the robot needs to do
  - Animals have evolved sensors that suited to their environment and position in the ecosystem

    $\Rightarrow$ A good robot designer should follow similar principles

- **Two possible questions:**
  - Given a sensory reading, what was the world like when the reading was taken?
  - Given a sensory reading, what should I do?

The Perception Problem

- **The first question**
  - Focused on world representation
  - Perception is considered in isolation
- **The second question**
  - Perception without the context of action is meaningless
  - Systemic view of the robot design
    - Task to perform
    - Best suited sensors
    - Most suited mechanical design

Some current sensing methods

- **Action oriented perception**
  - Direct link between perception and action
- **Expectation-based perception**
  - Sensor interpretation constraining based on world knowledge
- **Task-driven attention**
  - Direct perception where information is needed or likely to be provided (focus-of-attention)
- **Perceptual classes**
  - Partition world in manageable categories

What is a sensor?

- **Sensors constitute the perceptual system of the robot**
- **A sensor is a device that maps an physical attribute to a quantitative measure**
- **Sensors are essentially transducers that convert some form of energy into electrical energy that is then processed as a quantitative measure**
- **Transducer + electronics + ADC + software**

Human sensing

Sense	Physical attribute	Organ
Vision	EM waves	eyes
Audition	Pressure waves	Ears
Gustation	Chemical properties	Tongue
Olfaction	Chemical properties	Nose
Tact	Contact pressure/texture	Skin

- Humans can also sense other things like temperature, pain, equilibrium, own body
- Several animals have still other types of sensor capabilities

Robot sensors

- **Proximity**
  - Infrared, Sonar, laser, optical, capacitive, inductive
- **Position**
  - Potentiometer, switch, buttons, encoder
- **Heading**
  - Compass, gyroscope
- **Temperature**
  - Thermocouple
- **Sound**
  - Microphone
- **Force, Pressure**
  - Piezoelectric, variable resistance
- **Battery, Current**
  - Thermocouple
- **Chemical**
  - Several
- **Magnetic field**
  - magnetometer
- **Vision**
  - Camera
- **Etc…**

Levels of sensing

- **Attribute to be measured**
- **Physical principle of transduction**
  - Determines many of the characteristics of the sensor
- **Hardware**
  - Electronics
- **Software**
  - Signal processing
  - Computation
  - Sensor fusion

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Sensor Characteristics

- **Field of view and Range**
- **Accuracy, repeatability and resolution**
- **Responsiveness in the target domain**
- **Power comsumption**
- **Hardware reliability**
- **Size**
- **Computational complexity**
- **Interpretation reliability**

Sensor errors

- **Systematic errors**
  - Always push the measured value in the same direction
  - Can be reduced by sensor calibration
  - Ex: temperature in sonar, wheel radius in odometry
- **Non systematic errors**
  - Have a more random behavior
  - Cannot be predicted or eliminated by calibration

Classification of sensors

- **Passive sensors**
  - Rely on environment to provide the medium for observation
  - Ex: Camera, thermocouple, microphone
  - Less energy
  - Reduced Signal to Noise ratio
- **Active sensors**
  - Emits form of energy and measures the impact
  - Ex: sonars. X-ray
  - Restricted enviroments

Classification of sensors

- **Proprioceptive**
  - Measure values intenally to the system
  - Ex: motor speed, battery status, joint angle, etc.
- **Exteroceptive**
  - Information from the robots external environment
  - Generally considering the robots frame of reference

Proprioceptive sensors

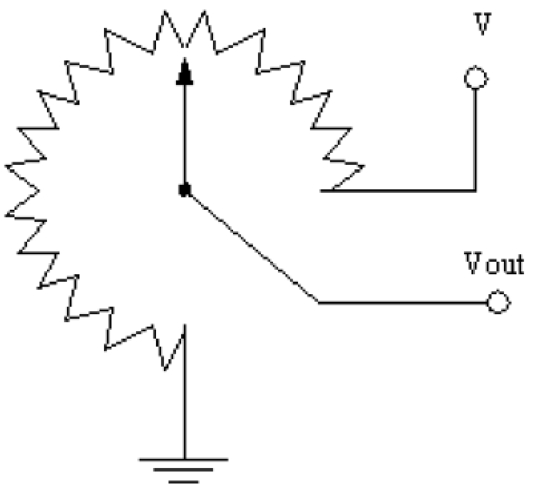
- **Potentiometers**
- **Encoders**
- **Inertial navigation system**
- **GPS**
- **Compass**
- **Gyroscopes**
- **Battery sensors**

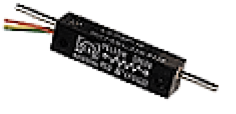
Potentiometer

- **Physical principle:**

  Linear tension variation at the output of a variable resistance

- **Can be used to detect angular or linear position**
  - Joint angle, servomotor, etc



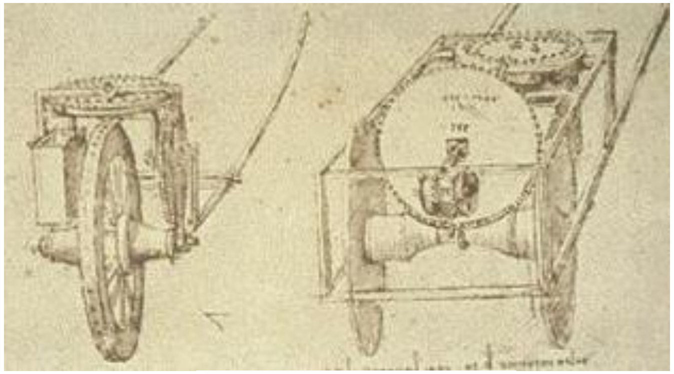


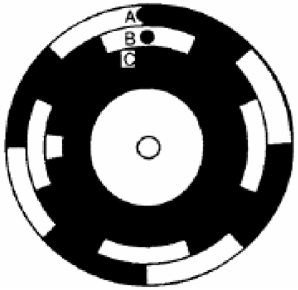
Encoders

- **Physical principle**

  Record the wheel traversed distance

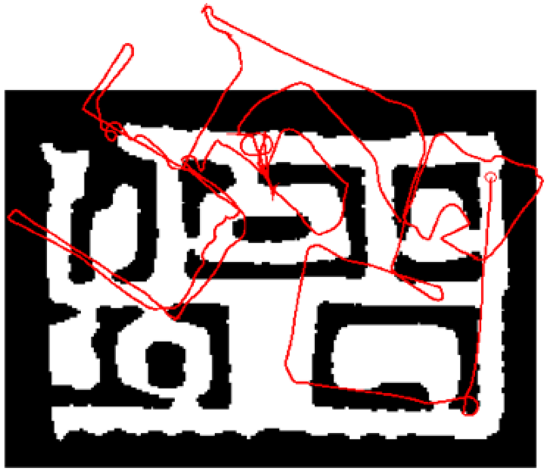
- **Wheel traversed distance is used to estimate robot position and orientation**

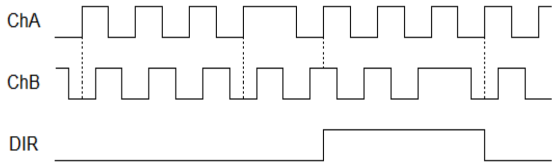




$$lin = \frac{v_l + v_r}{2}$$

$$rot = \frac{v_l - v_r}{D}$$





Detect direction of movement

GPS/DGPS

- **Physical principle**
  Triangulation over the distance to several satellites
- **Estimates longitude, latitude and altitude**
  – Resolution: 10-15m

- **DGPS (Differential GPS)**
  – Extra GPS receivers at known locations are used to reduce errors
  – Resolution: few centimeters

Proximity sensors

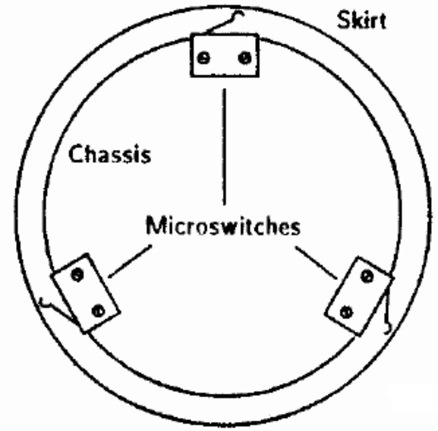
- **Bumper**
- **Infrared**
- **Sonar**
- **Laser Range Finder**

Bumper

- **Physical principle**

  Direct contact closes (or opens) a circuit

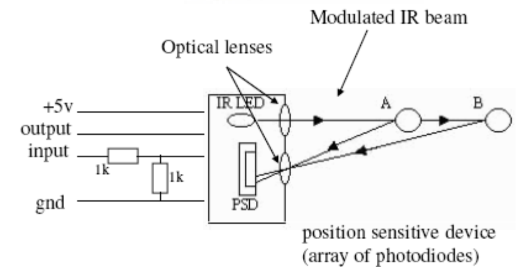
- **Used to detect collisions**
- **Binary value**
- **Reliable but the collision is eminent**



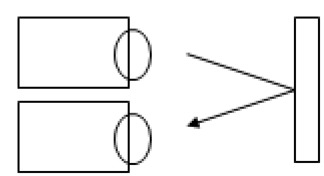
Infrared sensor

- **Physical principle**

  Na IR emitter/receiver is used
  to detect distance or as a barrier
- **Used to estimate distance , presence of objects or color**
  - Some dark surfaces do not reflect IR
- **Several technologies**
- **Range: from <10cm to ~1m**
- **Narrow field of view**
- **Cheap**



IR barrier



Sonar

- **Physical principle**

  Emit US chirp, time until echo is received is used to estimate distance

- **Time until echo is proportional to the distance**

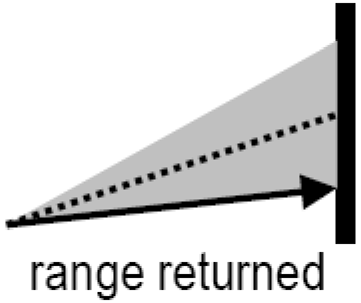
  closest obstacle

  – Speed of sound changes with temperature and pressure

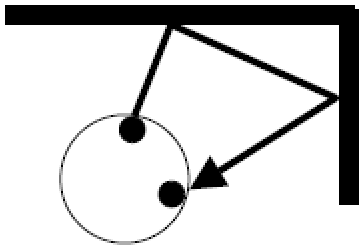
- **Range: few centimeters to ~10m**
- **Field of view ~30º**
- **Cheap (but not as cheap as IR)**
- **Fast (depends on range)**
- **Ring of sonars**

Sonar problems

- **Foreshortening**



- **Crosstalk**
  - Receiver may detect echoes from other sonars in the ring



- **Specular reflection**
  - Wave is reflected when angle is acute

Laser range finder

- **Physical principle**

  Similar to sonar but uses laser instead of sound

- **Time of flight is used to estimate distance**
- **Range: 2m until ~500m**
- **Resolution: 1 cm**
- **Field of view: 100º-180º**
- **Much more accurate than sonar**
- **Also more expensive**

Vision

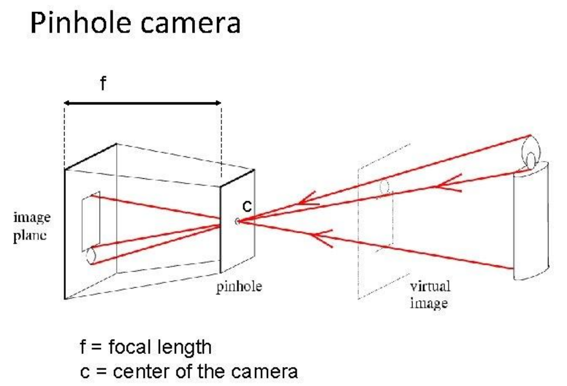
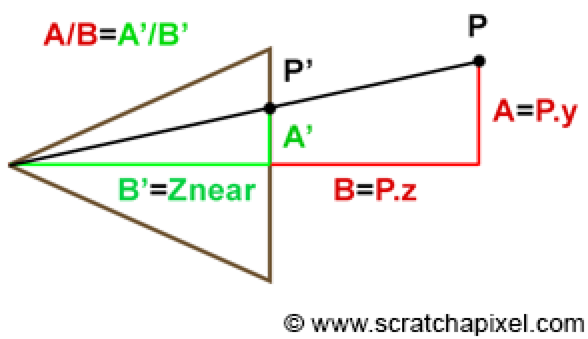


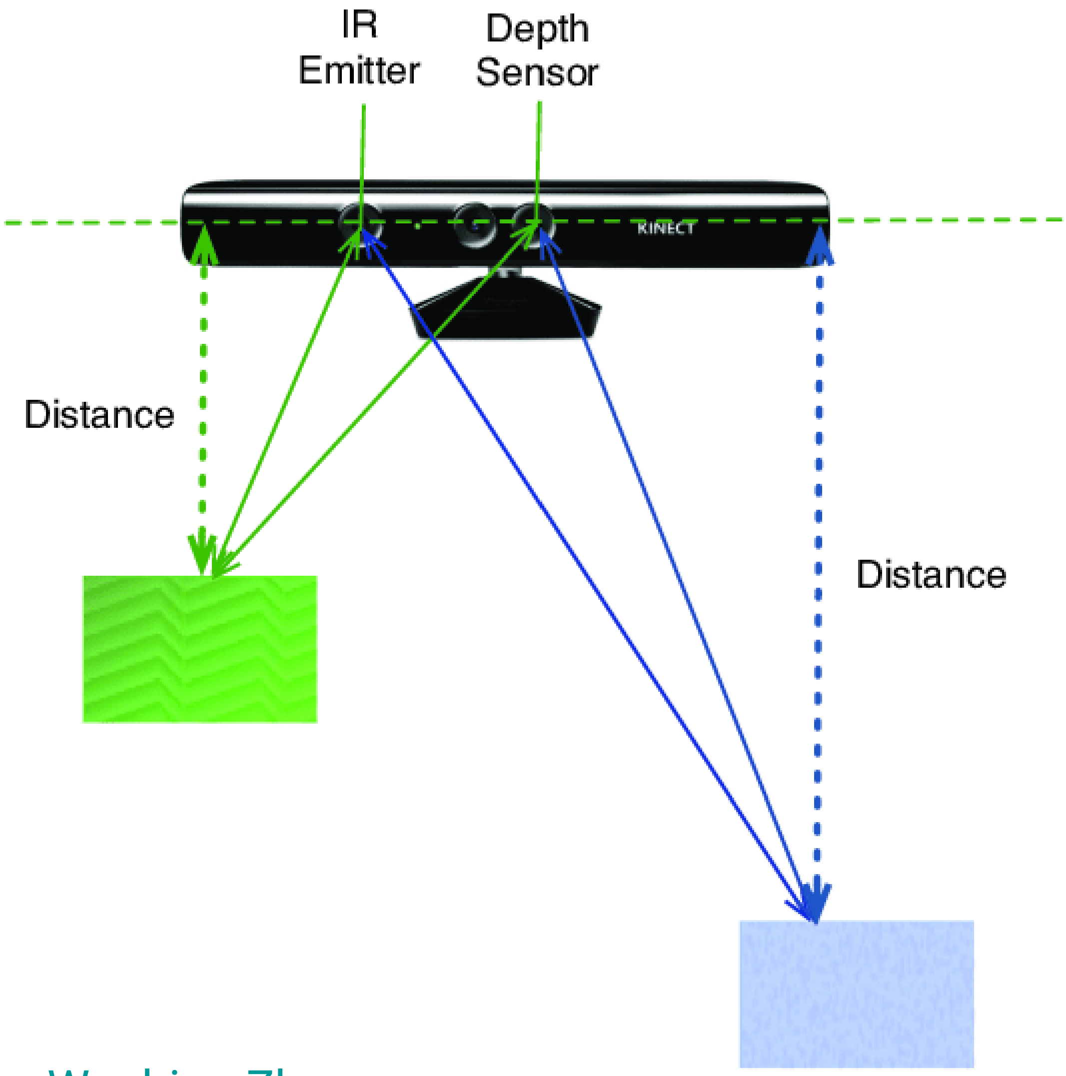
Figure from Forsyth

https://slidetodoc.com/pinhole-camera-model-computational-photography-derek-hoiem-university/

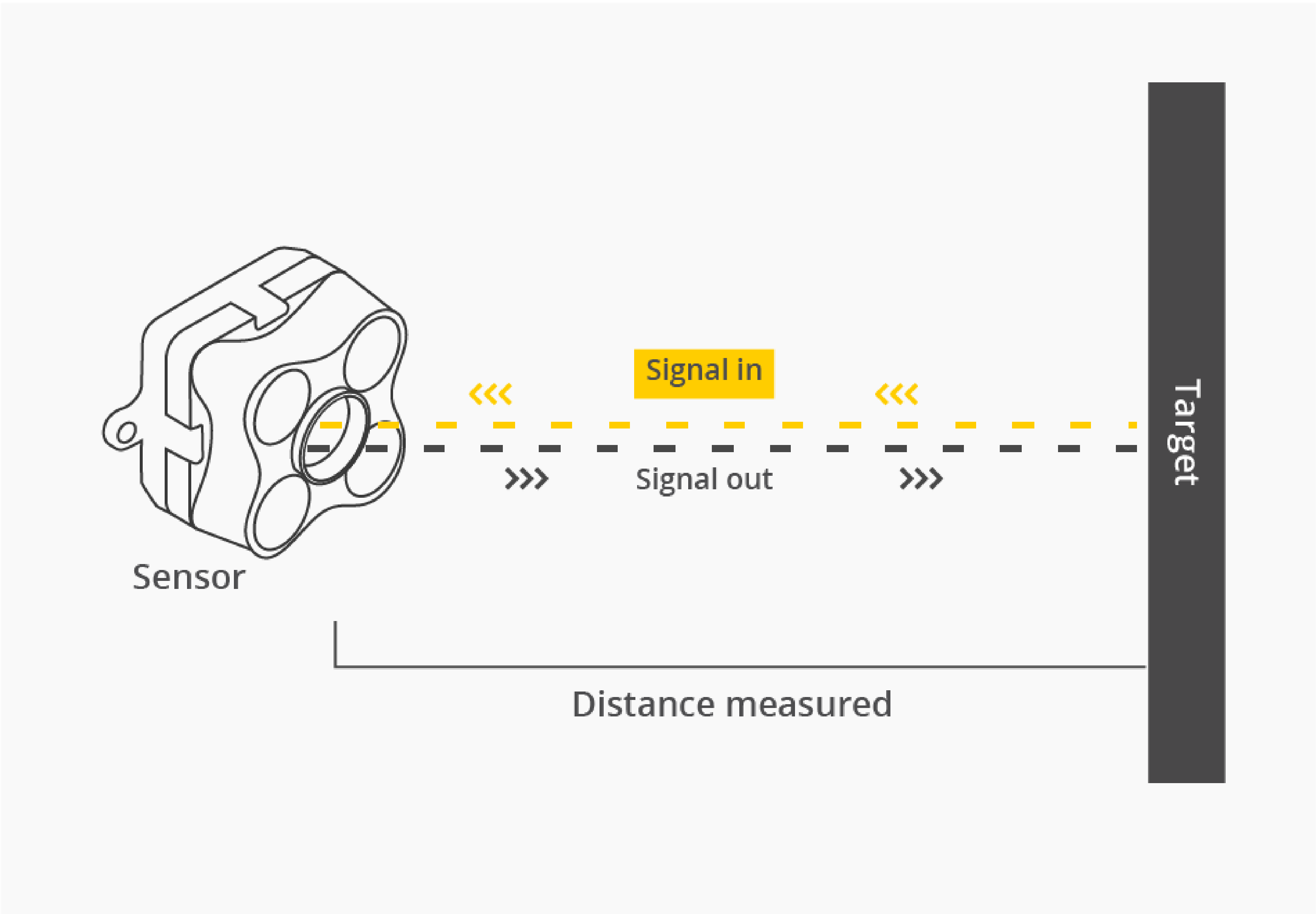


https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera/how-pinhole-camera-works-part-2

Depth Sensing

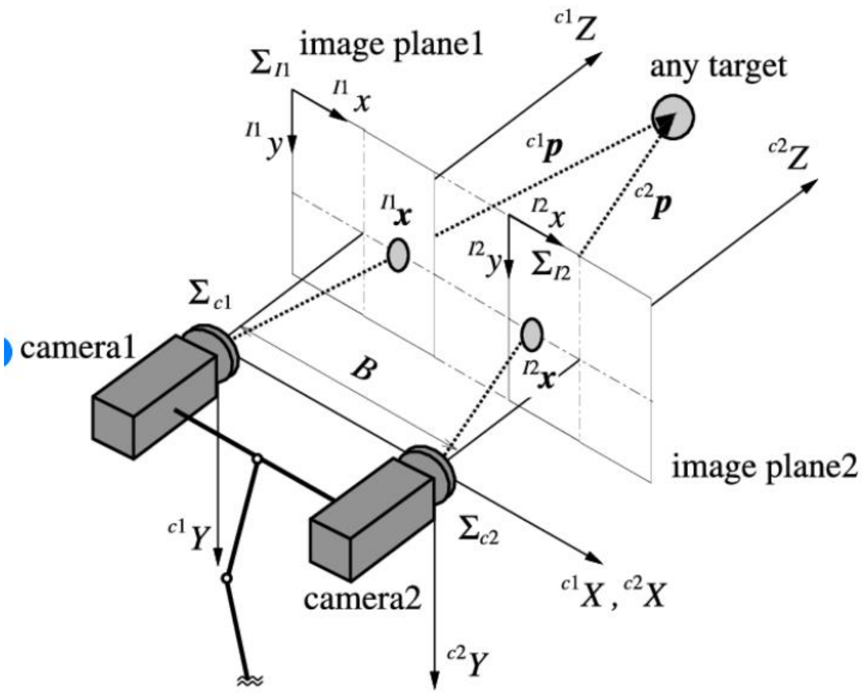


Depth Sensing



https://www.terabee.com/time-of-flight-principle/

Stereo Vision



Visual tracking of unknown moving object by adaptive binocular visual servoing 1999

DOI:10.1109/MFI.1999.815998

•IEEE Xplore

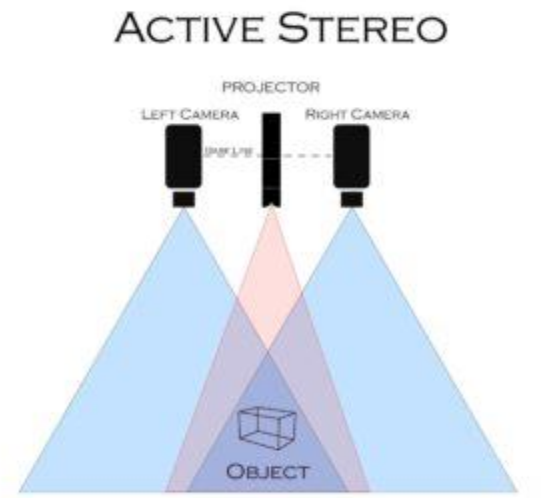
•Conference: Multisensor Fusion and Integration for Intelligent Systems, 1999

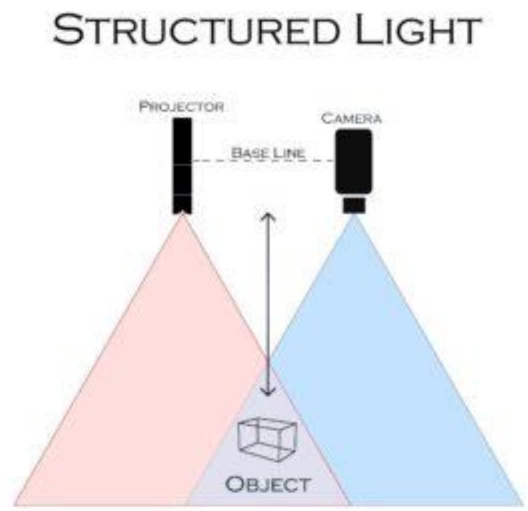
STEREOLABS

https://www.stereolabs.com/zed-2i/

https://www.stereolabs.com/solutions/robotics/

Active Stereo

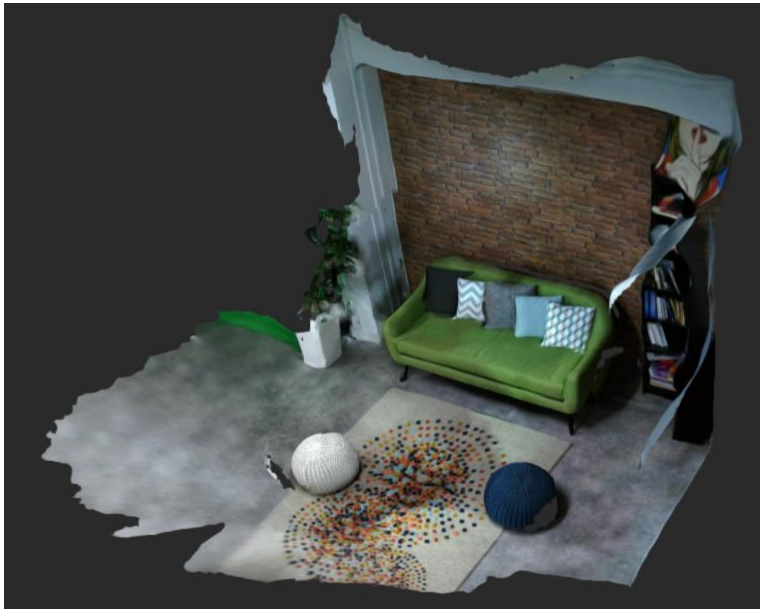




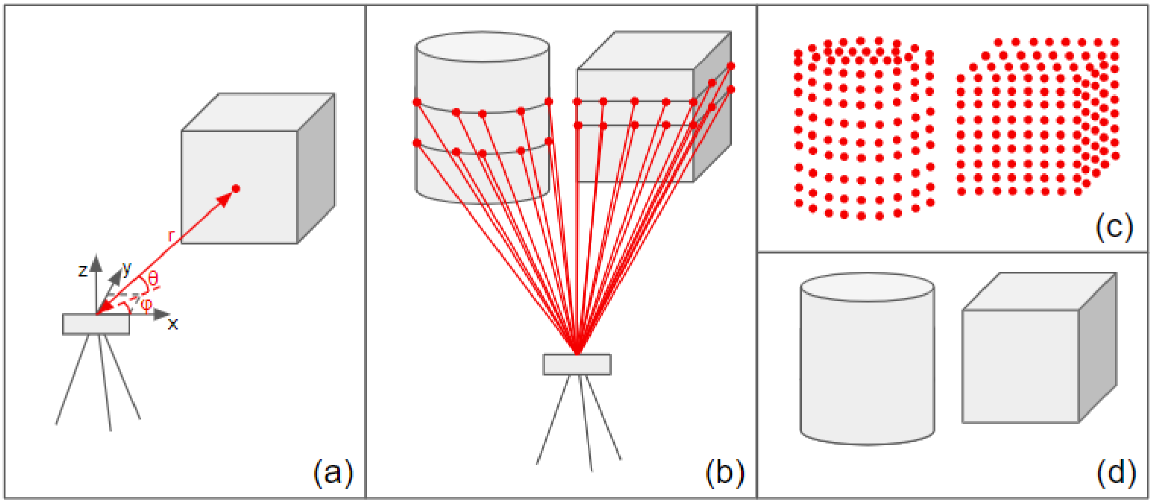
https://www.osela.com/depth-sensing/

RGBD

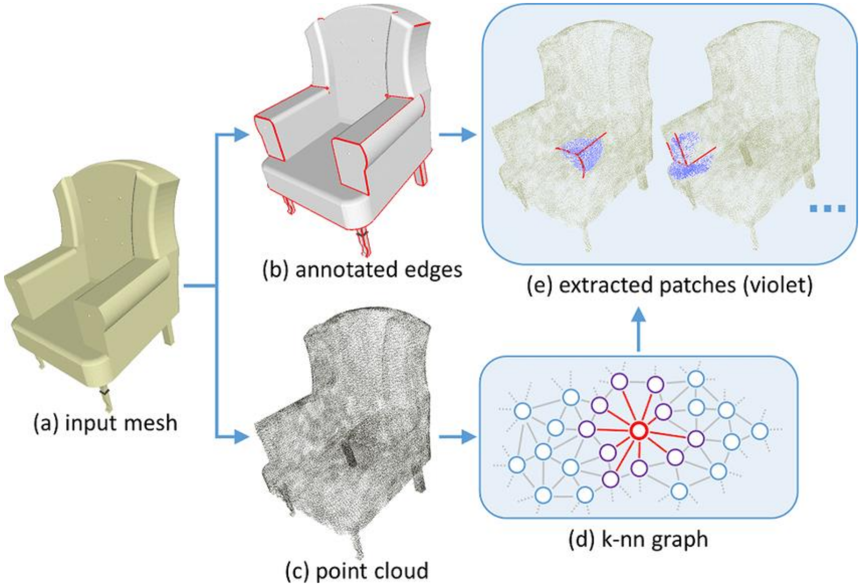
- https://p3d.in/ifOvj (interactive!)



RGBD – Point Cloud



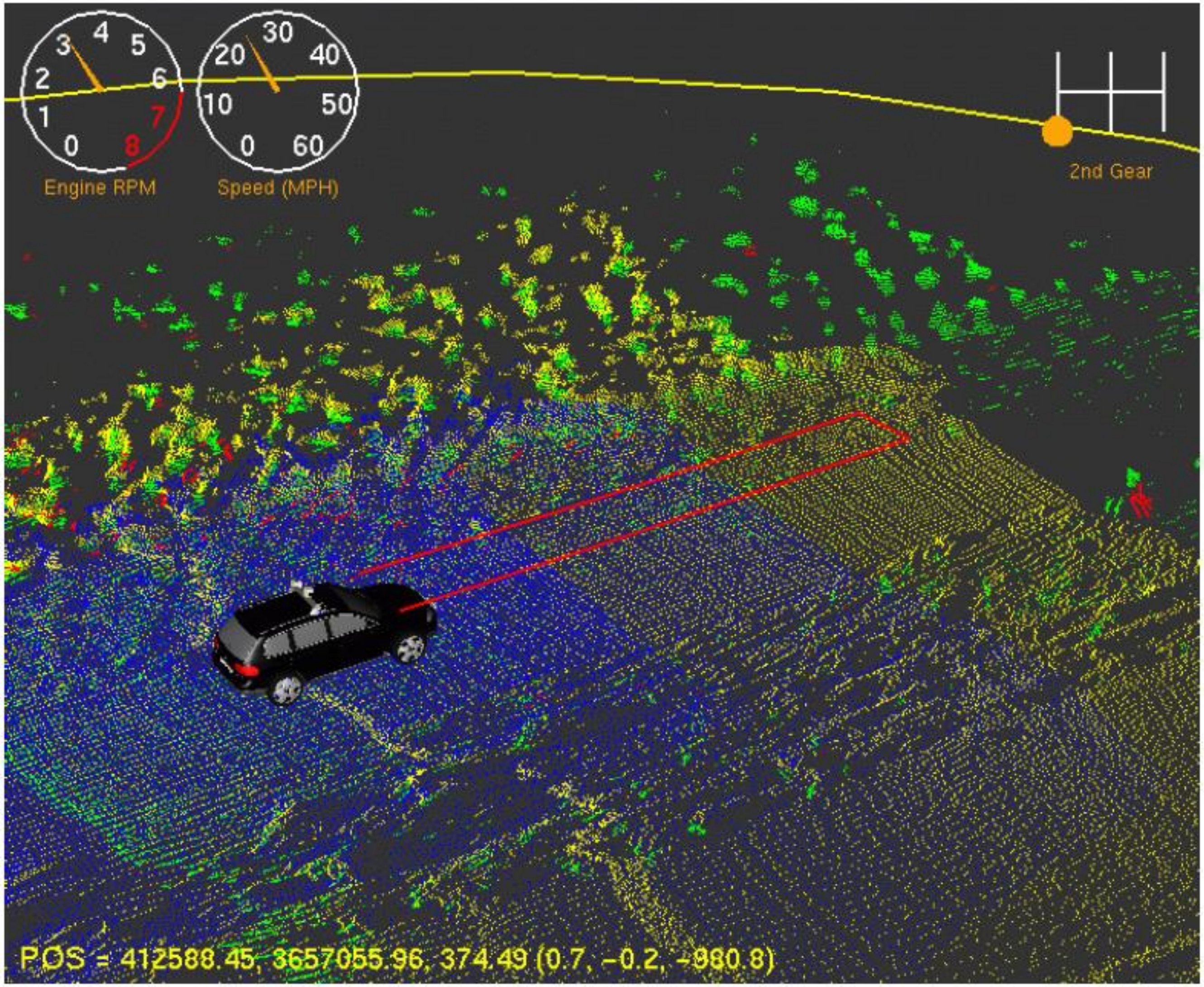
https://blog.bricsys.com/point-clouds-whats-the-point/



Yu, Lequan & Li, Xianzhi & Fu, Chi-Wing & Cohen-Or, Daniel & Heng, Pheng-Ann. (2018). EC-Net: an Edge-aware Point set Consolidation Network.

https://www.researchgate.net/publication/326459389_EC-Net_an_Edge-aware_Point_set_Consolidation_Network

Laser range finder

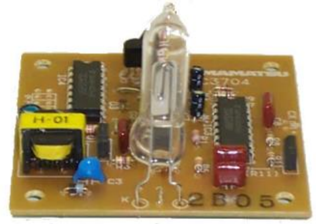


Thrun et al.

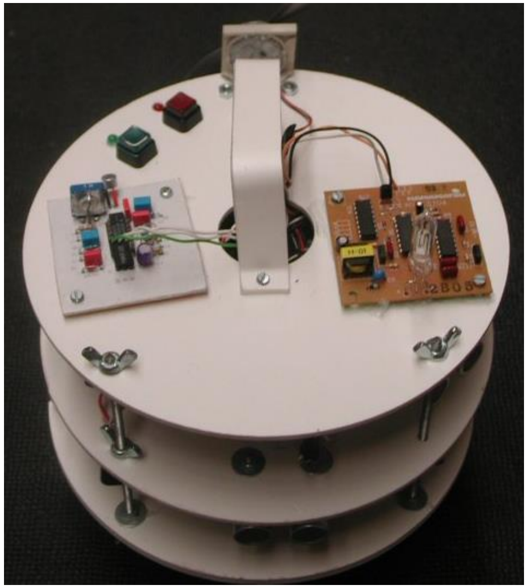
Fire detection sensors

- **Physical principle**

  Detect flame by sensing ultraviolet light



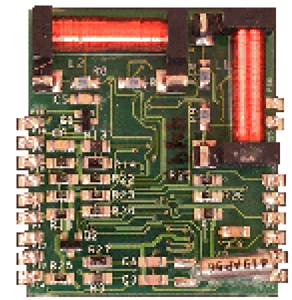
- **Flame detector, fire alarms, fire fighting competitions, etc**
- **Can detect a flame from a cigarette lighter from a distance of more than 5m**

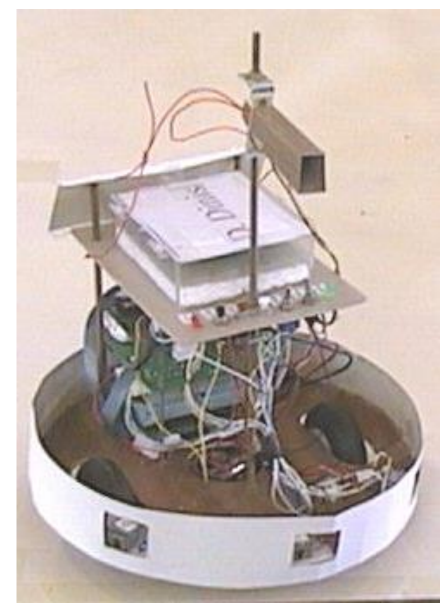


Compass

- **Physical principle**

  Detection of Earth magnetic field
- **Used to detect robot orientation**
- **Together with velocity information can be used for dead reckoning**
- **Resolution 1º, Accuracy 2º**
- **Sensitive to other magnetic fields ot metal in the environment**

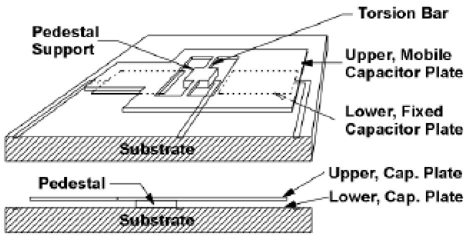


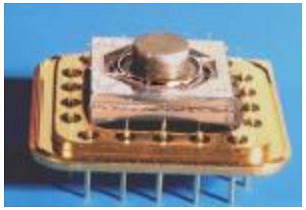


Inertial sensors

- **Accelerometer**
  - Measures the linear acceleration of the robot
  - Second integration to obtain displacement
- **Gyroscope**
  - Measures the angular motion of the robot
  - Not influenced by gravity
  - Integration gives angular displacement

DE-ACCM3D
3 axis accelerometer board





Multisensor fusion

- **Redundant**
  - Several sensors return the same percept
- **Complementary**
  - Provide disjoint types of information about percept
- **Coordinated**
  - Sequence of sensors
  - Focus-of-attention

Redundant Multisensor fusion

- **Mean of several measures**
  - Considering a normal distribution:

$$M \sim N(\mu,\sigma^2)$$

The mean of N measures as a reduced covariance

$$Mean = 1/N \sum_{n=1}^{N} M_i$$

$$Mean \sim N\left(\mu,\sigma^2/N\right)$$

Redundant Multisensor fusion

- **Kalman filter**
  - Integration of measures over time
  - Markovian assumption
  - Considers physics model and action model

$$x_t = P x_{t-1} + C u_t + q \qquad q \quad N(0, Q)$$

$$z_t = H x_t + r \qquad r \quad N(0, R)$$

$$N(\hat{x}_{t-1}, \Sigma_{t-1})$$

  - Forecast step

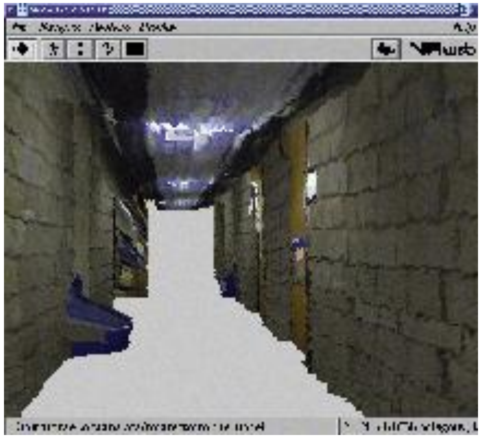
$$\begin{aligned} \bar{x}_t &= P \hat{x}_{t-1} + C u_t \\ \bar{\Sigma}_t &= P \Sigma_{t-1} P^{\mathrm{T}} + Q \end{aligned}$$

  - Information

$$\begin{aligned} K_t &= \bar{\Sigma}_t H^{\mathrm{T}} (H \bar{\Sigma}_t H^{\mathrm{T}} + R)^{-1} \\ \Sigma_t &= (I - K_t H) \bar{\Sigma}_t \\ \hat{x}_t &= \bar{x}_t + K_t (z_t - H \bar{x}_t) \end{aligned}$$

Complementary Multisensor fusion

- **Example: Mercator Project**
  - The robot
    - 2 Laser ranger finders
    - 1 omnicam
  - Laser ranger finders are used to detect distance to walls and obstacles
  - Output of omnicam is used to apply textures to the model



Intelligent Robotics

Sensors

That’s all folks ☺ !