



UNIVERSITÉ DE TECHNOLOGIE DE BELFORT-MONTBÉLIARD

Perception

RO51 - Introduction to Mobile Robotics

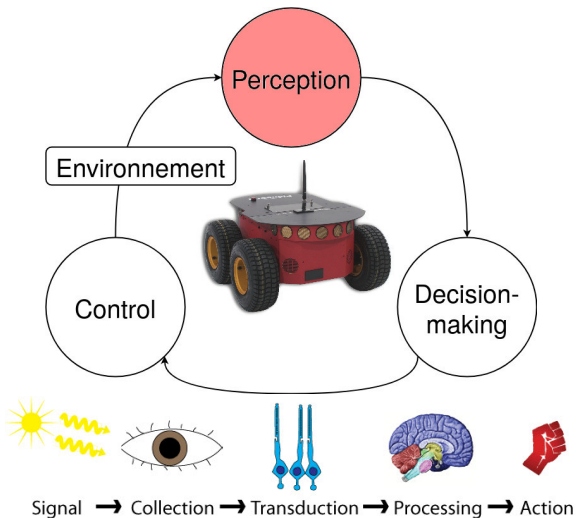
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<https://yzrobot.github.io/>

www.utbm.fr

Perception



Perception

- Mobile robots move around and interact with the physical world.
- The importance of perception can be easily understood by referring to humans themselves.
- Perception includes the perception of **the robot body and the outside world**.
- Perception is not mandatory for industrial robots.

Perception



Your 8 Senses



Sight



Hearing



Taste



Touch



Smell



Movement



Balance



Interoception

- Similar to the human nervous system.
- The five senses often said: for the outside world.
- The remaining three senses: for the robot itself.

Perception

- Robot perception relies on sensors:



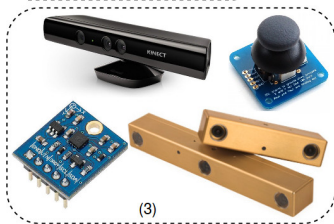
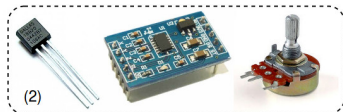
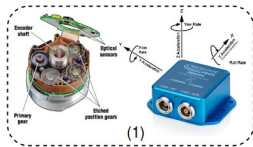
Sensors

- By definition, a sensor is a device that produces an output signal for the purpose of sensing of a **physical phenomenon**.
- By using sensors, a robot can perceive the environment, covering not only its exterior, such as the distance to an object, but also its own components (i.e. interior), such as the motor speed.
- From the perspective of usage, the sensors used by robots can be divided into two categories: **proprioceptive and exteroceptive sensors**.
- The current off-the-shelf sensors can be divided into **passive and active** types according to their action form (similar to electrical components).

Sensors

- Commonly used in mobile robots include:
 - Passive: measure energy coming directly from the environment, like human ability.
 - * Cameras (monocular, multi-ocular, RGB-D): intensity-based
 - * Tactile sensors (contact switches, bumpers): intensity-based
 - * Wheel/motor sensors (brush encoders, potentiometers): electricity-shift
 - Active: emit energy and measure the reaction, tools made by humans.
 - * Laser range finder: Time-of-Flight (ToF)
 - * Ultrasound: ToF
 - * Radar: ToF
 - * Infrared: phase-shift

Sensors



- ① Active proprioceptive: rotary encoder, inertial measurement unit (IMU)
- ② Passive proprioceptive: thermometer, potentiometer, accelerometer
- ③ Passive exteroceptive: camera, touch/haptic sensor, compass
- ④ Active exteroceptive: GPS, lidar, sonar, radar (not shown here)

Sensors

What do we get from sensors?

| | | |
|----------------|----|--------------------------------|
| rotary encoder | —> | angle |
| IMU | —> | acceleration and angular speed |
| thermometer | —> | temperature |
| potentiometer | —> | position |
| accelerometer | —> | acceleration |
| camera | —> | image |
| touch sensor | —> | contact |
| compass | —> | magnetism |
| lidar | —> | distance |
| sonar | —> | distance |
| radar | —> | distance and velocity |
| GPS | —> | geolocation |

Sensors

What can sensors be used for?

- Human detection and tracking: video
- Human detection and skeleton tracking: video
- Mapping: video 1, video 2
- Localization: video

Sensors

Performance characteristics

- Basic sensor response ratings:
 - **Dynamic range**: the upper and lower limits of a sensors input values.
 - **Resolution**: the minimum difference between two values that can be detected by a sensor.
 - **Linearity**: whether the input and output are linear (a straight line).
 - **Bandwidth / Frequency**: the speed at which the sensor provides data (typically in Hertz). ← very important for mobile robots

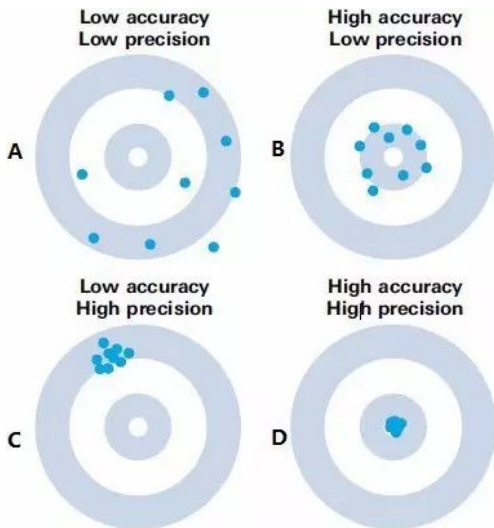
Sensors

Performance characteristics

- In situ sensor performance:
 - **Sensitivity**: the degree to which a change in the input signal changes the output signal. ← double-edged sword
 - **Cross-sensitivity**: the sensitivity to types other than the type of target being measured. ← lower is better
 - **Error**: the difference between measured and true values.
 - * **Systematic errors**: deterministic, predictable, introduced by poor modeling of the sensor, e.g. poor calibration.
 - * **Random errors**: stochastic, hard to predict, e.g. electromagnetic interference.
 - **Accuracy**: the ability to produce measurements with little error.
 - **Precision**: the ability to reproduce a measurement when presented with the same input. ← often confused with accuracy

Sensors

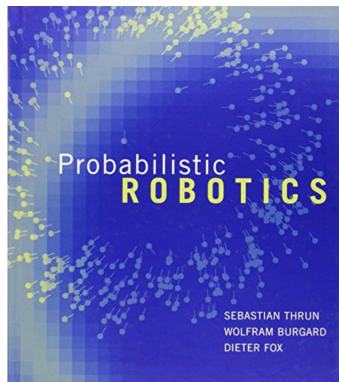
Accuracy vs. Precision



Sensors

Face the error

- Mobile robots depend heavily on exteroceptive sensors.
- We have to face the reality that sensors are not perfect.



Sebastian Thrun



Wolfram Burgard



Dieter Fox

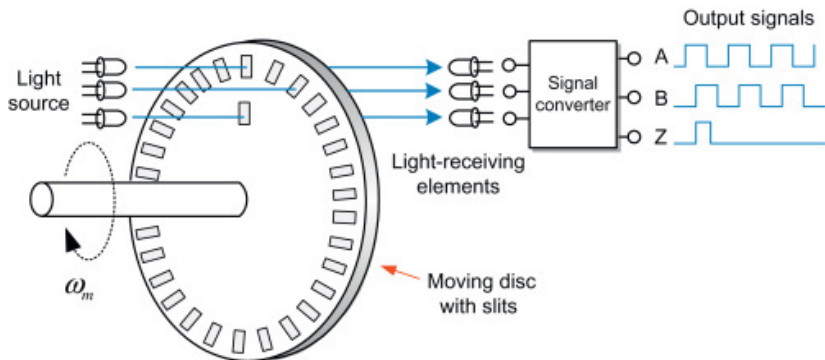
Sensors

- Some sensors that will be touched upon in later lessons:
 - **Wheel encoder**: provide odometry, very useful for robot localization, i.e. answering the question of where am I.
 - **IMU**: provide orientation, angular velocity, and linear acceleration.
 - **GPS**: provide latitude, longitude, and altitude, sometimes position covariance.

 - **Lidar / Laser rangefinder**: provide distance measurement.
 - **Sonar / Ultrasonic**: provide distance measurement.
 - **Radar**: provide distance and velocity (by Doppler effect) measurements.
 - **Camera**: provide color and texture.

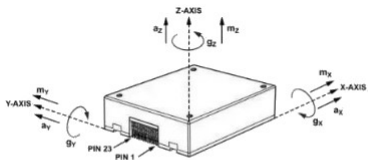
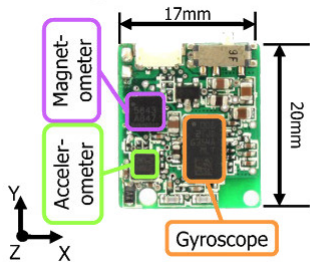
Sensors

Wheel encoder



Sensors

IMU



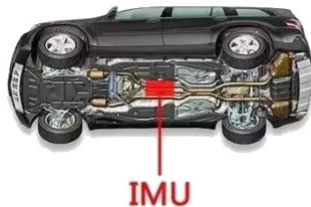
3-axis accelerometer (linear)
3-axis gyroscope (rotation rate)

6DOF

9DOF

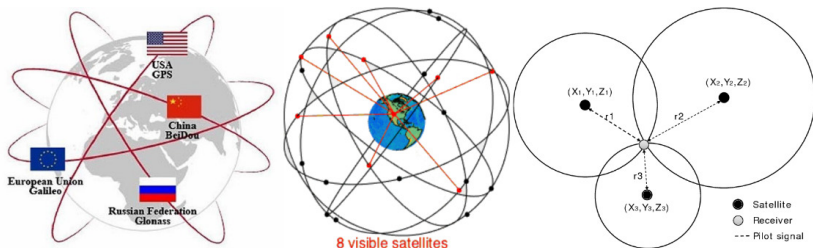
10DOF

3-axis magnetometer (magnetic field)
Barometer (altitude)



Sensors

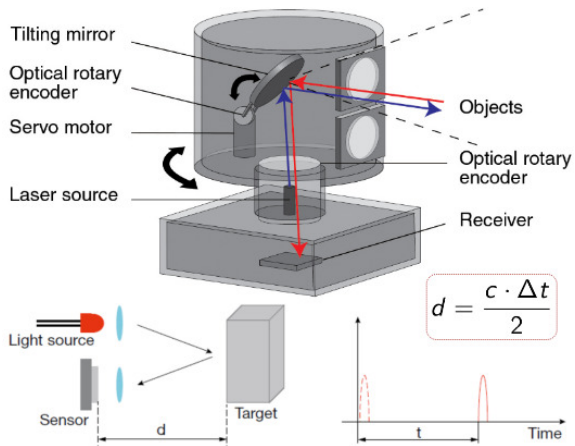
GPS



- Working principle: **trilateration (true-range multilateration)**
- $3 \times 10^8 \text{ m/s}(T - T_1) = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2}$
- $3 \times 10^8 \text{ m/s}(T - T_2) = \sqrt{(X - X_2)^2 + (Y - Y_2)^2 + (Z - Z_2)^2}$
- $3 \times 10^8 \text{ m/s}(T - T_3) = \sqrt{(X - X_3)^2 + (Y - Y_3)^2 + (Z - Z_3)^2}$
- $3 \times 10^8 \text{ m/s}(T - T_4) = \sqrt{(X - X_4)^2 + (Y - Y_4)^2 + (Z - Z_4)^2}$
- => Positioning requires at least 3 satellites (large error), generally 4 satellites (small error).

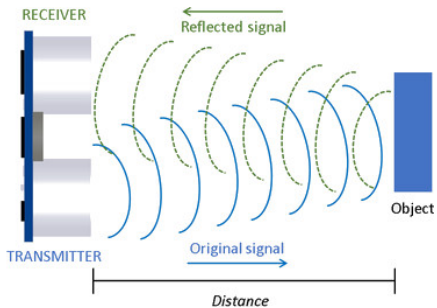
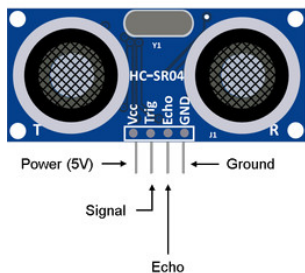
Sensors

Lidar



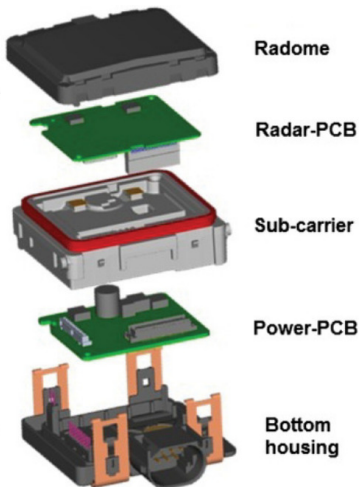
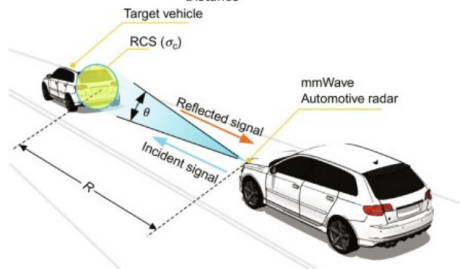
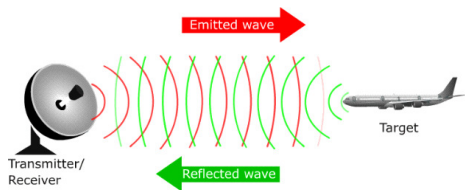
Sensors

Sonar



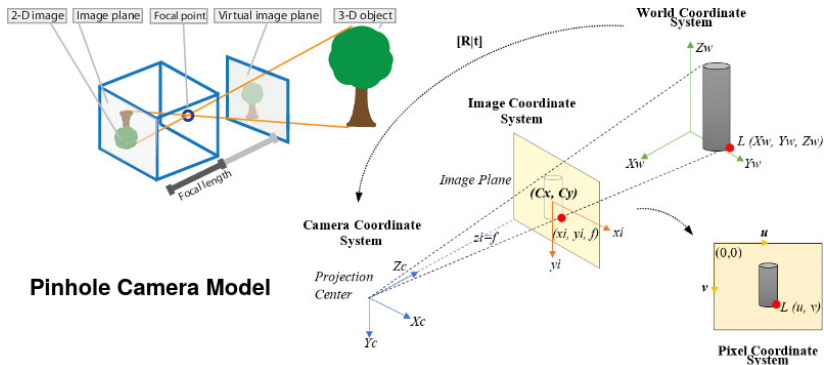
Sensors

Radar



Sensors

Camera



Pinhole Camera Model

Sensors

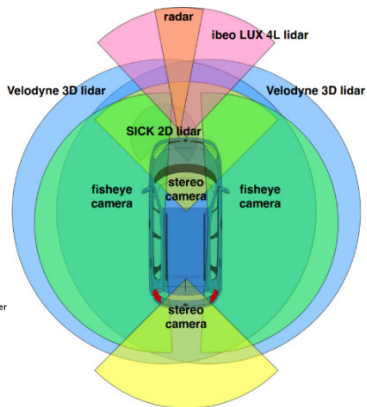
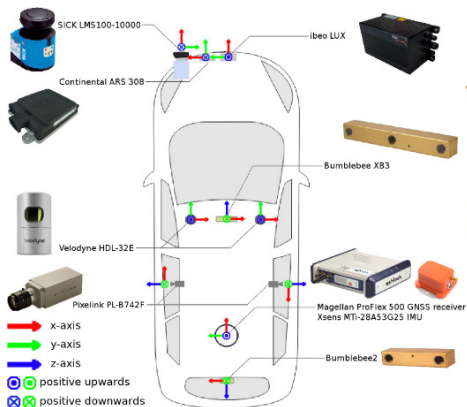
Which one to use?

| Sensors | Pros | Cons |
|---------|---|--|
| Lidar | <ul style="list-style-type: none"> - high positioning accuracy - fast data collection - can be used day and night | <ul style="list-style-type: none"> - high equipment cost - high computational cost - ineffective during rain/etc. |
| Sonar | <ul style="list-style-type: none"> - almost all material types - near object detection - unaffected by the weather | <ul style="list-style-type: none"> - low positioning accuracy - slow data collection - sensitive to temperature |
| Radar | <ul style="list-style-type: none"> - reliable detection - unaffected by the weather | <ul style="list-style-type: none"> - low positioning accuracy - slow data collection |
| Camera | <ul style="list-style-type: none"> - low equipment cost - providing intuitive images | <ul style="list-style-type: none"> - low positioning accuracy - affected by lighting |

- There is no almighty and perfect sensor, they all have limitations and edge cases.
- Because different sensors have different physical properties and each category has its own pros and cons.

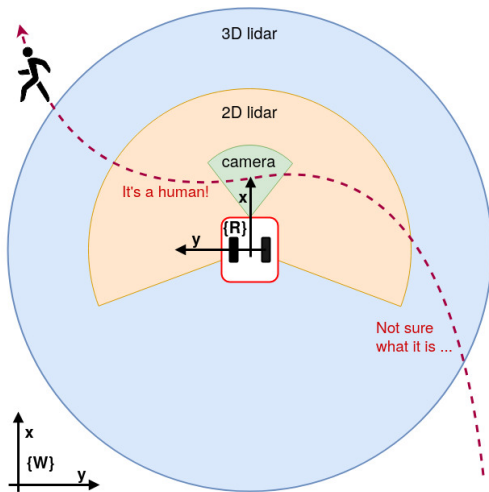
Sensors

Then?



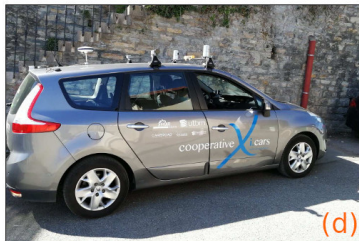
Sensors

Then?



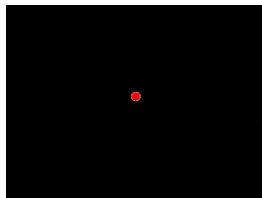
Sensors

Lidar



Sensors

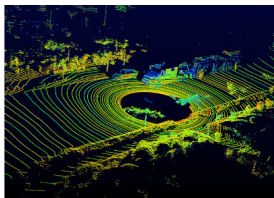
Lidar



1D



2D



3D

- 1D: point
- 2D: plane
- 3D: point cloud

Sensors

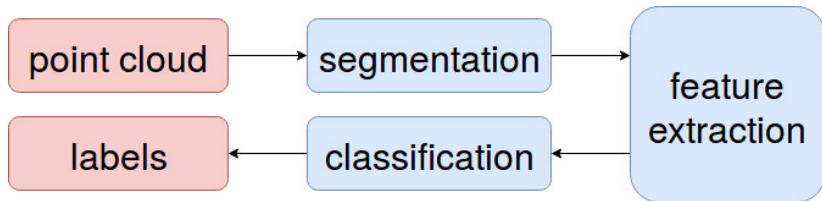
What can we do with lidar data?

- **Mapping and localization:** as shown in the previous videos, will be further explored later in the lectures on SLAM, exploration, and navigation.
- **Object detection:** problem about knowing where an object is (e.g. in coordinates) and its class, sometimes we are also interested in its geometric characteristics, such as size.
 - Conventional methods: usually pipe structures, identify objects based on geometrical features.
 - Emerging methods: Deep learning-based, usually with an end-to-end structure.

Sensors

Object detection

- Conventional methods:
 - **Segmentation**: split point cloud into clusters (ideally, each cluster corresponds to one object).
 - **Feature extraction**: general characteristics of a class of objects (size, material, and more).
 - **Classification**: which cluster corresponds to which category.
 - **Labels**: car, pedestrian, cyclist, etc.



Sensors

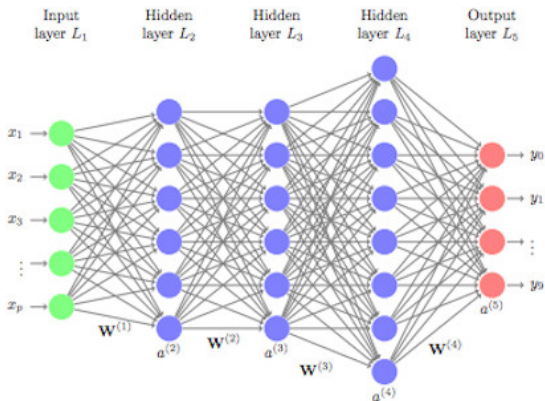
Object detection

- Segmentation: video
 - Thresholding
 - Clustering
 - Region growing
 - etc.
- Classification: video
 - Support Vector Machine (SVM)
 - Random forest
 - AdaBoost
 - etc.

Sensors

Object detection

- Emerging methods:
 - $\{x_1, x_2, \dots, x_n\}$: point cloud
 - $\{y_1, y_2, \dots, y_n\}$: labels



Sensors

Object detection

- Conventional methods:
 - Pros: explainable, process controllable, can be based on CPU only.
 - Cons: performance bottleneck.
- Emerging methods:
 - Pros: groundbreaking performance.
 - Cons: difficult to explain, process not controllable, usually rely on GPU.

Summary

- Robot perception relies on various sensors.
- Multimodal sensor system is the consensus of academia and industry.
- Perception is a big topic and the most challenging problem in robotics.
- Machine learning is an important approach.

The end

Thank you for your attention!

Any questions?