SENSORS FOR ROBOTS

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What is sensing?

Collect information about the world

Why Do Robots Need Sensors?

- Provides “awareness” of surroundings
- Allows interaction with environment
- Protection & Self-Preservation
- Gives the robot capability to goal-seek

Sensors

- Electrical/ Mechanical/ Chemical device
- Maps an environmental attribute to a quantitative measurement
- Based on a transduction principle - conversion of energy from one form to another

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What Can Be Sensed?

- Light
- Sound
- Heat
- Chemicals
- Object Proximity
- Physical orientation/attitude/position
- Magnetic & Electric Fields
- Resistance (electrical, indirectly via V/I)
- Capacitance (via excitation/oscillation)
- Inductance (via excitation/oscillation)

Classification of Sensors

Internal state (proprioception) / external state (exteroceptive)

- Feedback of robot internal parameters, e.g. battery level, wheel position, joint angle, etc.
- Observation of environments, objects

Active / non-active

- Emitting energy into the environment: radar, sonar
- Passively receive energy to make observation: camera

Contact / non-contact

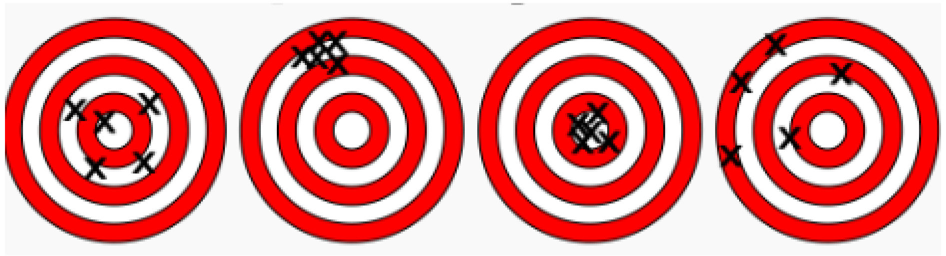
Visual / non-visual

Robot Sensor Characteristics

- Crucial for choosing the suitable sensor for the robot
- Affect the price range

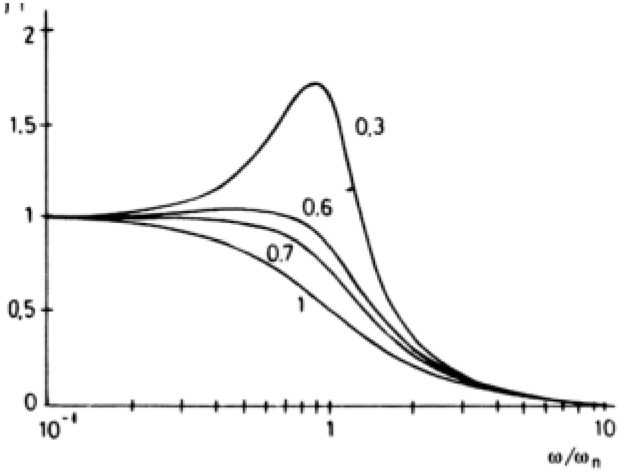
Static characteristics:

- Accuracy
- Resolution
- Precision
- Errors
- Drift
- Sensitivity
- Linearity
- Hysteresis (backslash)



Dynamic characteristics:

- Zero order systems
- First order systems
- Second order systems



Sensors used in robot navigation

Resistive sensors
- bend sensors, potentiometer, resistive photocells

Tactile sensors
- contact switch, bumpers...

Infrared sensors
- Reflective, proximity, distance sensors...

Ultrasonic Distance Sensor

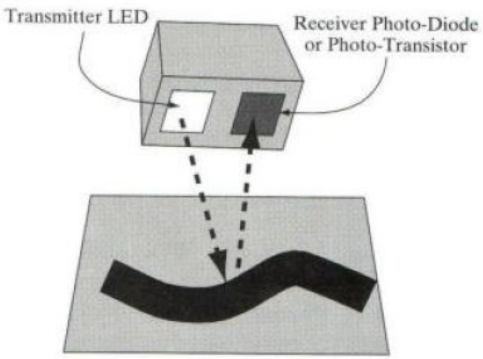
Inertial Sensors (measure the second derivatives of position)
- Accelerometer, Gyroscopes,

Orientation Sensors
- Compass, Inclinometer

Laser range sensors

Vision

Global Positioning System



Case study: Summit-XL Steel

SUMMIT-XL STEEL

Base with standard mecanum wheels (100 Kg payload capacity) and IMU MyAHRS+. Including CPU i5 and Motherboard MI02-30 + i7 10/11h generation processor + 32GB RAM + 250GB M.2 SSD. Without Battery, without Sensors.

250 KG OF PAYLOAD

INDOOR ENVIRONMENT

RESISTANT STAINLESS STEEL

STANDARD COMPONENT OPTIONS*	Retail price
CPU i7	650 €
Mecanum strong wheels (payload 250 Kg)	1.750 €
Mecanum + rubber wheels (both sets)	1.495 €
Battery LiFePO4 pack 30Ah@48V	2.495 €
Battery LiFePO4 pack 15Ah@48V	1.250 €
IMU VectorNav	1.995 €
Remote emergency stop (Tyro)	1.495 €
4G Router Rutx11	750 €
Front camera : option 1 Orbbec Astra S RGBD camera	320 €
Front camera : option 2 ZED2 camera + GPU	1.995 €
Front camera : option 3 RealSense D435	550 €
Additional camera : PTZ Axis M5074	695 €
Additional camera (x2) : PTZ Axis M5074 (x2)	1.390 €
GPS ARDUSIMPLE	1.250 €
GPS ARDUSIMPLE LR with base station	1.795 €
Scannerlaser : Option 1 Safety Pack (x2 2D safety scanner + safety PLC)	9.995 €
Scannerlasers (pack of 2 LiDARs) : Option 2 TIM 551 (x2)	3.530 €
Scannerlasers (pack of 2 LiDARs) : Option 3 TIM 561 (x2)	3.850 €
Scannerlasers (pack of 2 LiDARs) : Option 4 TIM 571 (x2)	5.070 €
Scannerlasers (pack of 2 LiDARs) : Option 5 UST10LX (x2)	3.050 €
Scannerlasers (pack of 2 LiDARs) : Option 6 UST20LX (x2)	4.880 €
Scannerlasers (pack of 2 LiDARs) : Option 7 UST30LX (x2)	8.290 €
Scannerlaser (single LiDAR) : Option 8 TIM 551 (x1)	1.765 €
Scannerlaser (single LiDAR) : Option 9 TIM 561 (x1)	1.925 €
Scannerlaser (single LiDAR) : Option 10 TIM 571 (x1)	2.535 €
Scannerlaser (single LiDAR) : Option 11 UST10LX (x1)	1.525 €
Scannerlaser (single LiDAR) : Option 12 UST20LX (x1)	2.440 €

IMU (Inertial Measurement Unit)

- Consists of a combination of accelerometers, gyroscopes, and magnetometers
- Used to track the robot's motion, estimate its position and velocity, and stabilize its orientation
- Useful in indoor environments or areas with poor GPS signal reception
- Use with LiDar and GPS to improve the accuracy of the robot's navigation and positioning

– Triple axis 16-bit gyroscope : ± 2000 dps
– Triple axis 16-bit accelerometer : ± 16 g
– Triple axis 13-bit magnetometer : ± 1200 μT
* On board software
– Exteneded Kalman filter
– max 100 Hz output rate
Attitude : Euler angle, Quaternion
Sensor : acceleration, rotation rate, magnetic field

MyAHRS+
US$75.00

2.0° Magnetic Heading Accuracy	**5-7°/hr (typ.)** Gyro In-Run Bias Stability	**400 Hz** Onboard Extended Kalman Filter Update Rate
0.5° Pitch/Roll Accuracy	**< 0.04 mg** Accel In-Run Bias Stability	**800 Hz** IMU Data

VN100

US$1300

LiDar (Light Detection and Ranging)

- Uses laser beams to measure the distance to surrounding objects
- Creates a 3D map of the environment
- Long range / short range
- 2D / 3D
- Field of View (FoV)
- Points Per Second

Tim 561

€ 3850

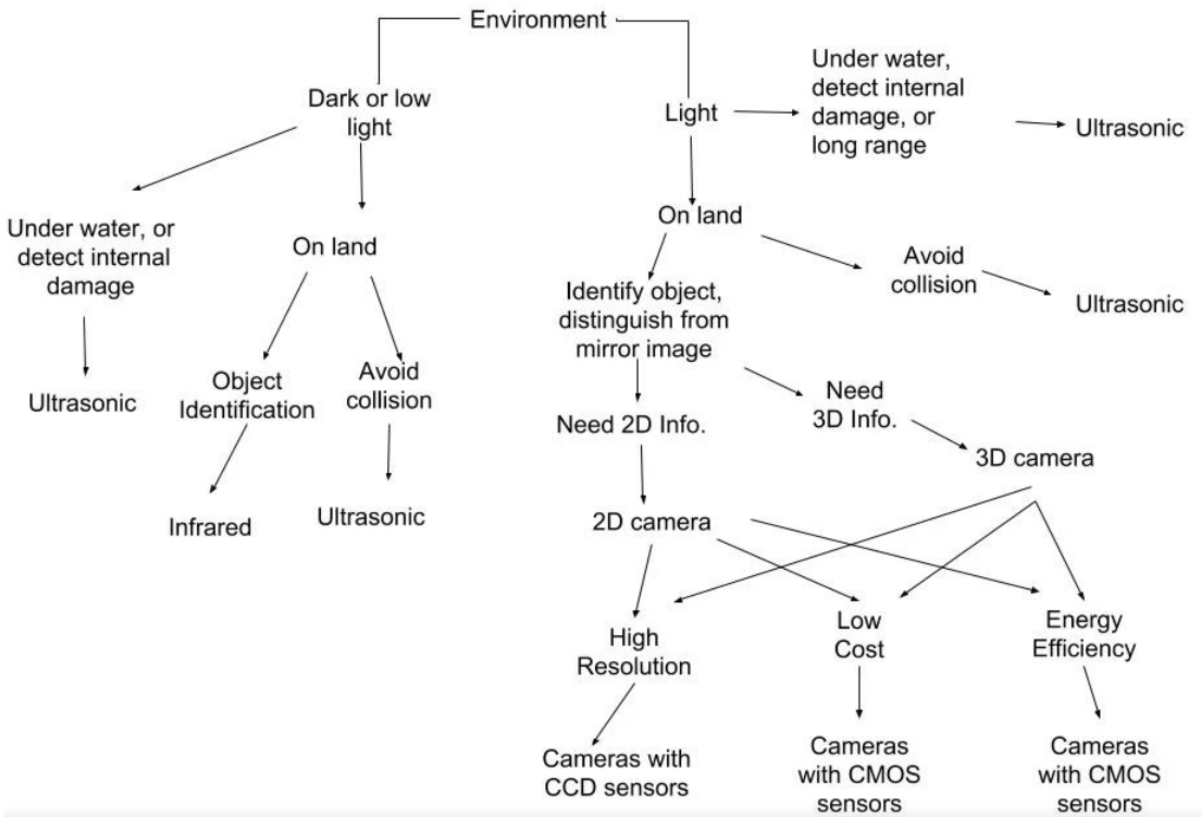
Aperture angle	
Horizontal	270°
Scanning frequency	15 Hz
Angular resolution	0.33°
Working range	0.05 m ... 10 m
Scanning range	
Response time	1 scan, typ. 67 ms 2 scans, ≤ 134 ms
Detectable object shape	Almost any
Systematic error	± 60 mm 2)
Statistical error	< 20 mm 2)

Detection range and object	0.05m to 30m(*2) (white kent sheet) 0.05m to 12m(*2) (diffuse reflectance 10%) Max. detection distance : 60m Min. detection size: 180mm(10m)、350mm(20m
Accuracy	±40mm (*2)
Repeated accuracy	σ< 20mm (*2)
Scan angle	270°
Scan speed	25msec (motor speed 2400rpm)
Angular resolution	0.25°

UST30LX € 8290

Camera

- Essential for the robots to navigate the landscape and avoid collisions with nearby objects
- Include 2D imaging, 3D sensing, ultrasonic, and infrared



	Ultrasonic	Infrared	3D Sensing
Accuracy	Good	Good	Great
Data replicability	Great	Good	Good
Resolution	Good	Good	Great
Requires minimum range (cannot be too close)?	Yes	No	No
Range	Longest	Longer	Short
Affected by light?	No	Somewhat	Yes
Affected by dust?	No	No	Yes
Can detect internal damage?	Yes	No	No
Works underwater?	Yes	No	No
Distinguish object from its mirror image?	Yes	Yes	No
Distinguish between multiple objects?	Fair	Good	Great
Can measure distance?	Yes	Yes	Yes

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Camera	
Output Resolution	Side by Side 2x (2208x1242) @15fps 2x (1920x1080) @30fps 2x (1280x720) @60fps 2x (672x376) @100fps
Field of View	Max. 110°(H) x 70°(V) x 120°(D)
Interface	USB 3.0/2.0 - Integrated 1.2m cable
Depth Range	0.3 m to 20 m (1 to 65.6 ft)
Depth Accuracy	< 1% up to 3m < 5% up to 15m

Sensors	
Motion	Gyroscope, Accelerometer Magnetometer
Environmental	Barometer Temperature

Physical	
Dimensions	175 x 30 x 33 mm (6.89 x 1.18 x 1.3")
Weight	166g (0.36 lb)
Operating Temp.	-10°C to +45°C (14°F to 113°F)
Power	380mA / 5V USB Powered

ZED 2 (+gpu)
€ 1995

Intel® RealSense™ Depth Camera D435/D435i Features	• Intel® RealSense™ Vision Processor D4 • Up to 1280 x 720 stereo depth resolution • Up to 1920 x 1080 RGB resolution • Depth diagonal field of view over 90° • Dual global shutter sensors for up to 90 FPS depth streaming • Range 0.2 m to over 3 m (varies with lighting conditions) • Intel® RealSense™ Depth Camera D435i includes Inertial Measurement Unit (IMU) for 6 Degrees of Freedom (6DoF) data

Intel RealSense Depth Camera D435

€ 550

Thanks for your attention

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Proprioceptive sensors measure values internal to the robot; for example,

- motor speed,
- wheel load,
- robot arm joint angles, and
- battery voltage.

Exteroceptive sensors acquire information from the robot's environment; for example,

- distance measurements,
- light intensity, and
- sound amplitude.
- Hence, exteroceptive sensor measurements are interpreted by the robot in order to extract meaningful environmental features.

1. **Accuracy:** Accuracy should be high. How close output to the true value is the accuracy of the device.
2. **Precision :**There should not be any variations in the sensed output over a period of time precision of the sensor should be high.
3. **Operating Range:** Sensor should have wide range of operation and should be accurate and precise over this entire range.
4. **Speed of Response:** Should be capable of responding to the changes in the sensed variable in minimum time.
5. **Calibration:** Sensor should be easy to calibrate, time and trouble required to calibrate should be minimum. It should not require frequent recalibration.
6. **Reliability:** It should have high reliability. Frequent failure should not happen.
7. **Cost and Ease of operation :**Cost should be as low as possible, installation, operation and maintenance should be easy and should not required skilled or highly trained persons.

- **Gyroscopes**
  - Measure the rate of rotation independent of the coordinate frame
  - Common applications:
    - Heading sensors, Full Inertial Navigation systems (INS)
- **Accelerometers**
  - Measure accelerations with respect to an inertial frame
  - Common applications:
    - Tilt sensor in static applications, Vibration Analysis, Full INS Systems

Accelerometers

- They measure the inertia force generated when a mass is affected by a change in velocity.
- This force may change
  - The tension of a string
  - The deflection of a beam
  - The vibrating frequency of a mass