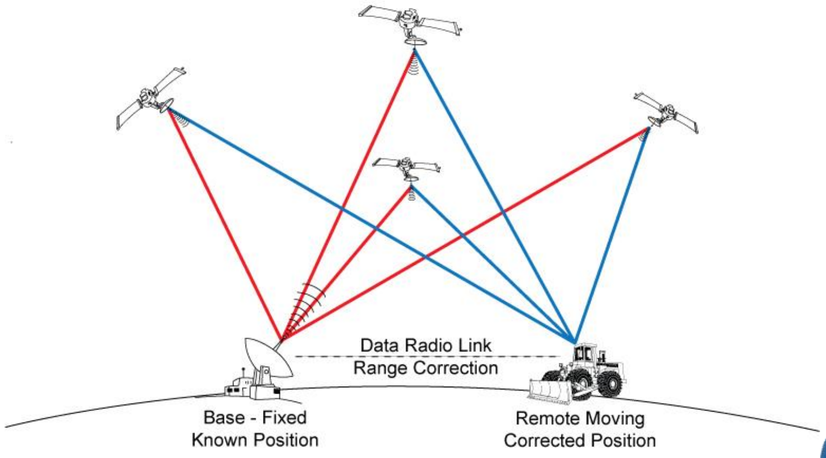
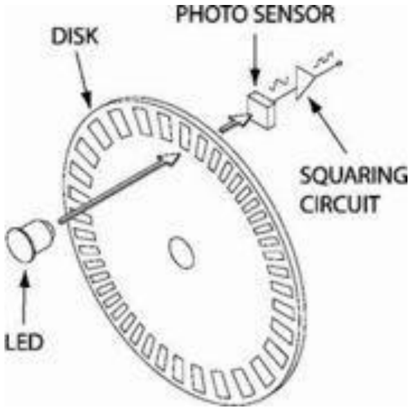
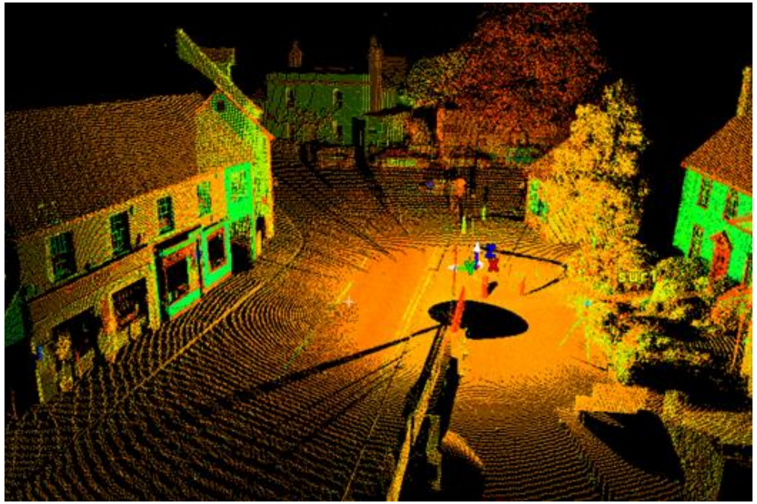
Aalto-yliopisto
Aalto-universitetet
Aalto University



Position sensors

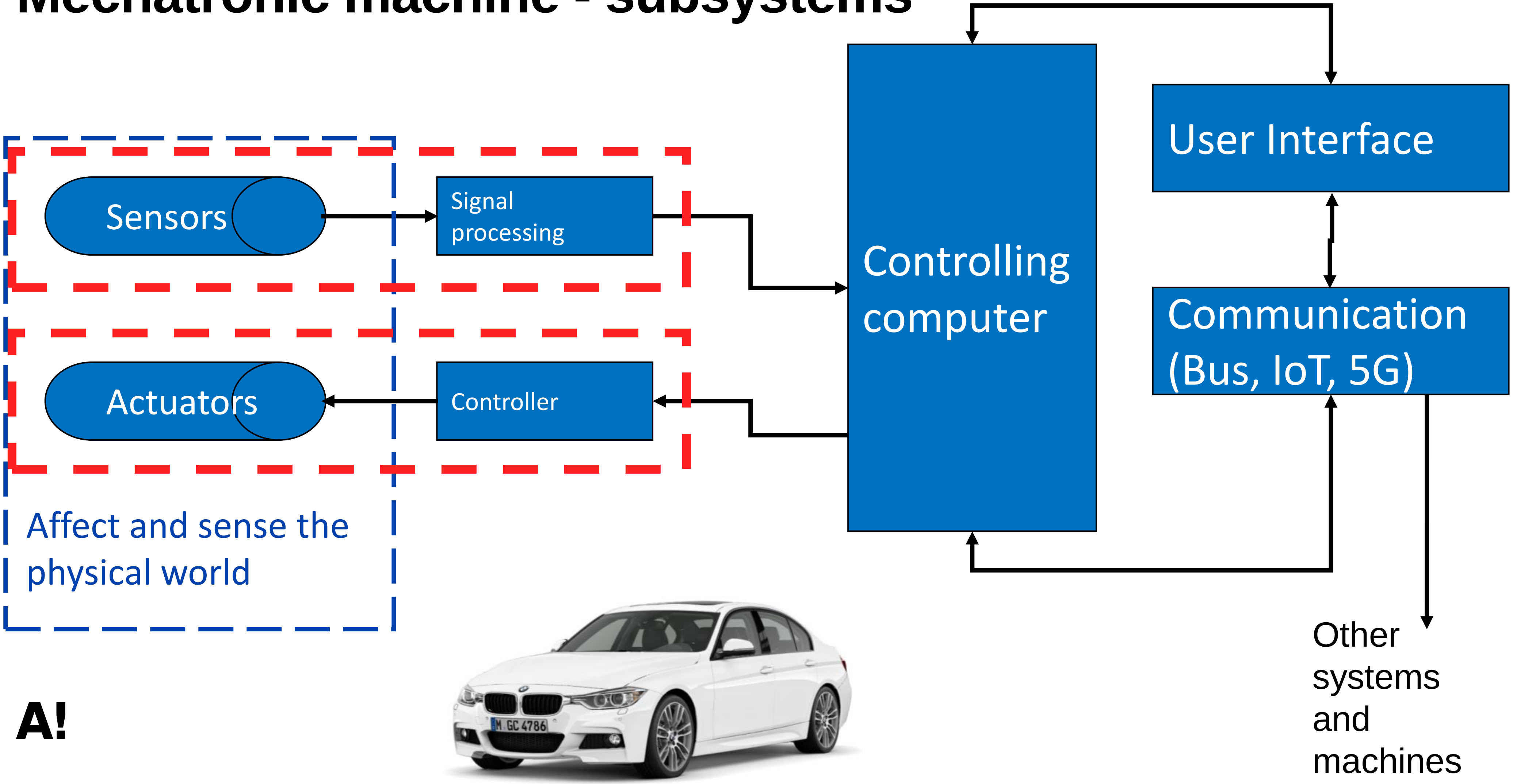
KON-C2004 Mechatronics Basics





Raine Viitala 29.10.2024

Mechatronic machine - subsystems



Learning outcomes

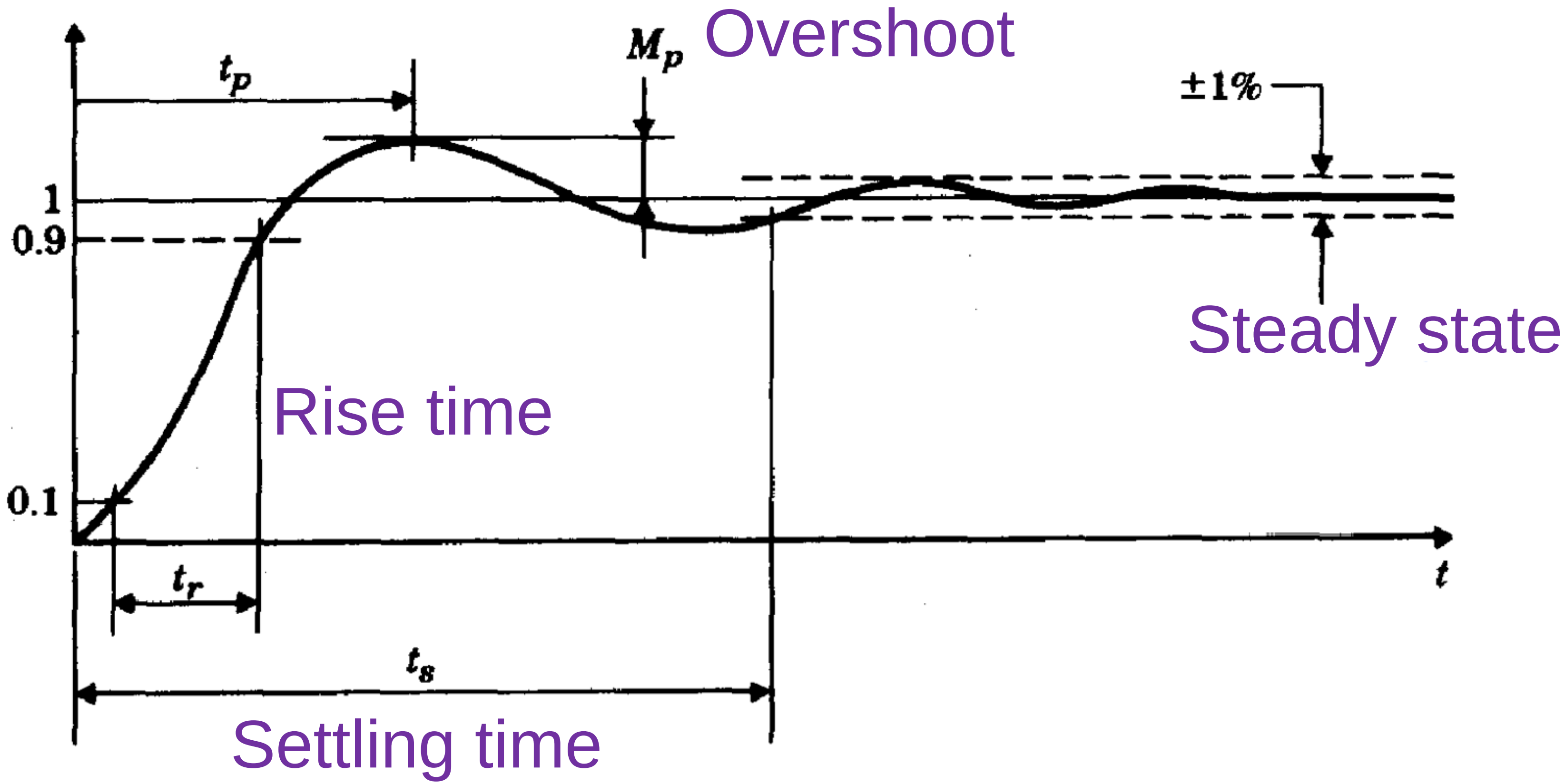
After the lecture, student should

- understand what sensor is
- understand the basic operating principles of typical position sensors
- understand response time, linearity and accuracy vs. resolution
- know the limitations of different sensor types
- know many everyday position sensors

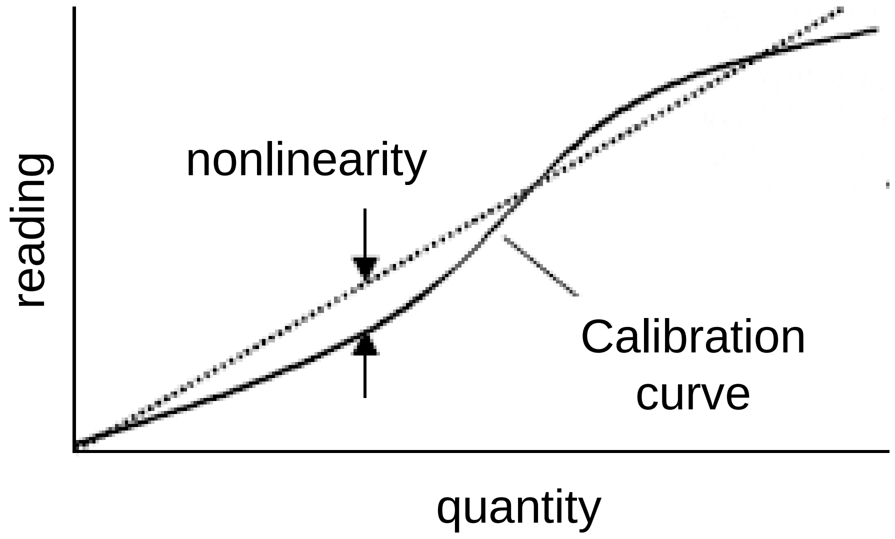
Important terms

Sensor	Detects a parameter and reports it in other form
Response time	Rise time of the output signal (often 10-90 %)
Range	Minimum and maximum amplitude of the measurement (on the linear and accurate area of the sensor)
Linearity	How linearly the output of the sensor follows the measured quantity change

Response time = Rise time



Linearity



Accuracy vs. precision vs. resolution

Accuracy

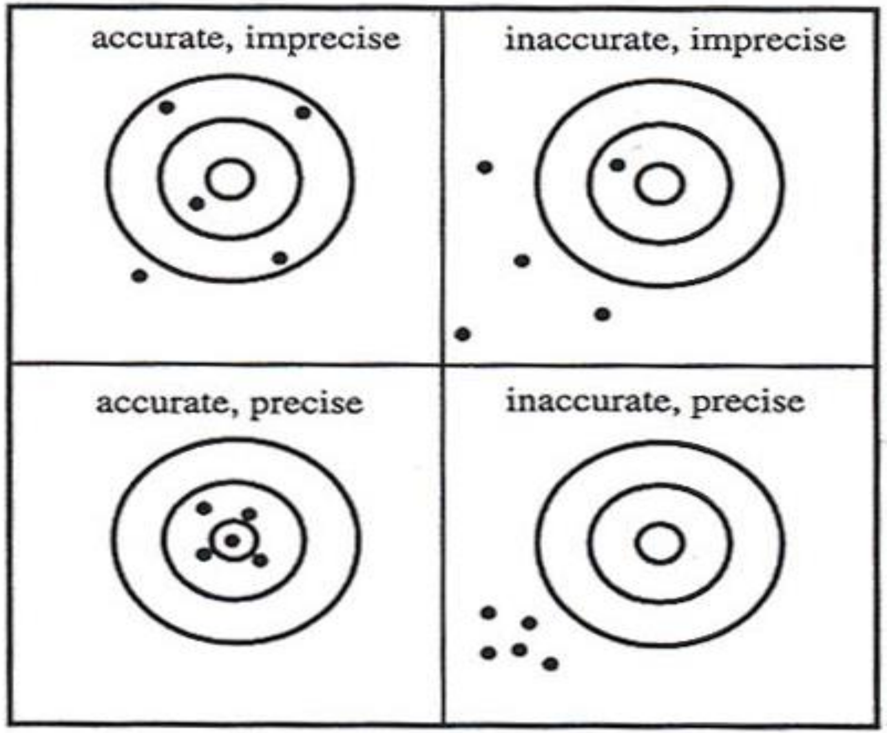
- The ability to produce a response or a reading that is close to the true value

Precision

- Random variation is minimized

Resolution

- Smallest detectable change



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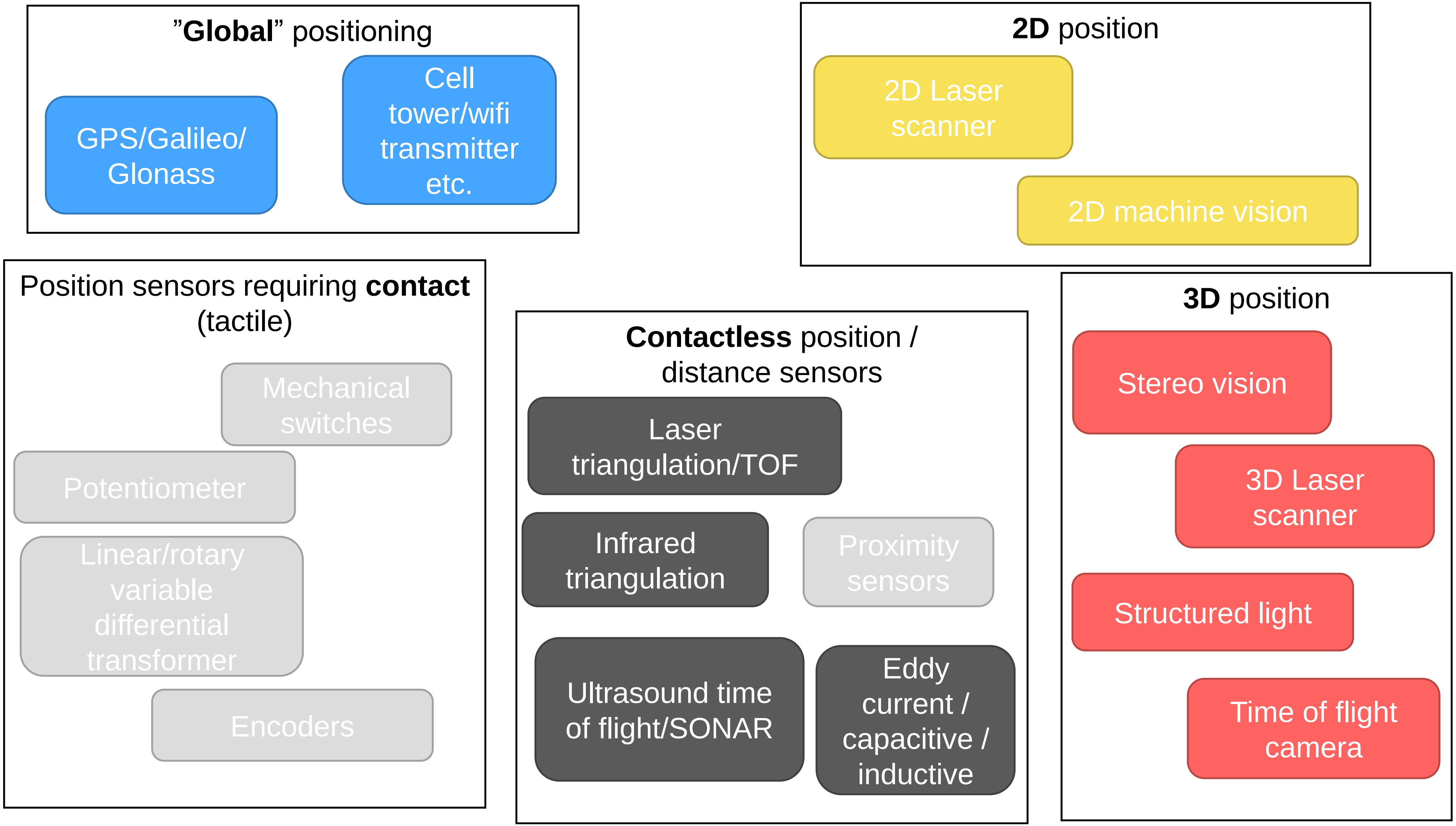
"Global" positioning
GPS/Galileo/ Glonass
Cell tower/wifi transmitter etc.
2D position
2D Laser scanner
2D machine vision
Position sensors requiring contact (tactile)
Mechanical switches
Potentiometer
Linear/rotary variable differential transformer
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Infrared triangulation
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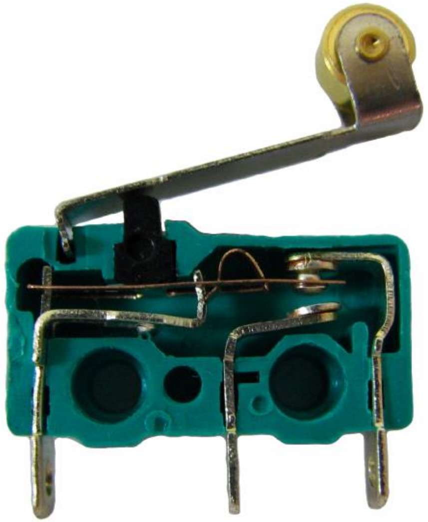
Eddy current / capacitive / inductive
3D position
Stereo vision
3D Laser scanner
Structured light
Time of flight camera

Switches

Binary switches (on/off)

- Signal changes when circuit is opened or closed



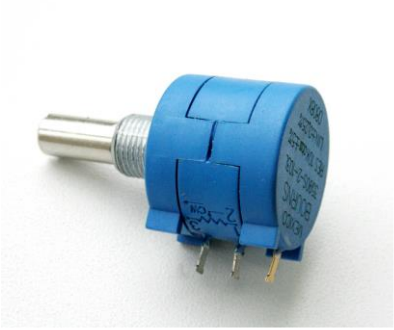
Potentiometer

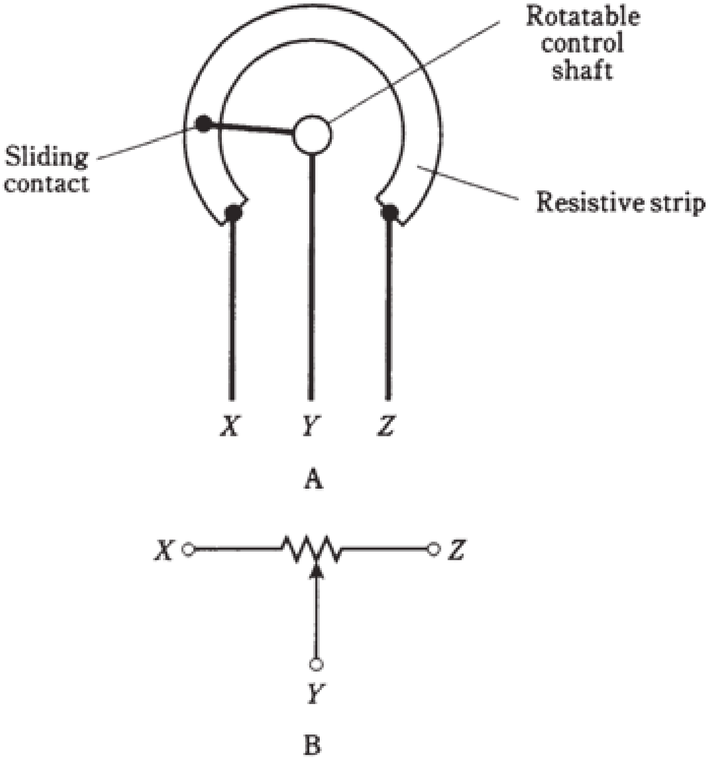
Angular or linear position

- Single or multi-turn

Low cost

Can wear out





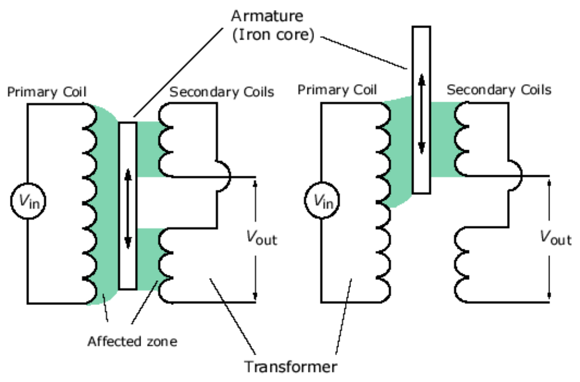
LVDT

Linear Variable Differential Transformer

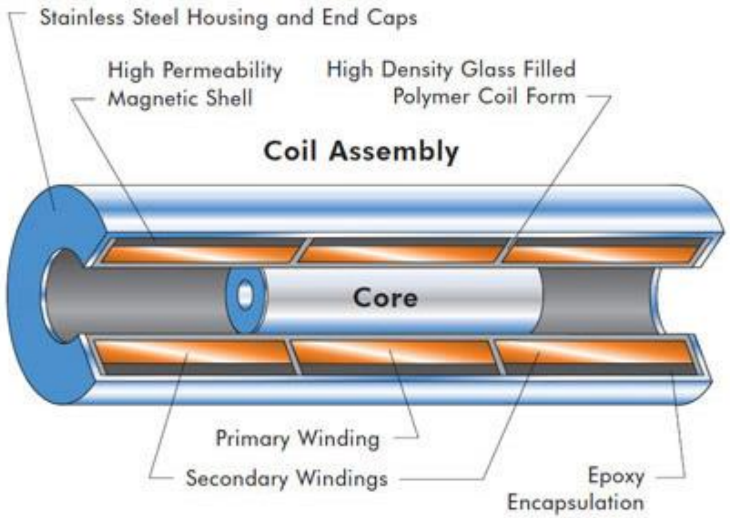
- High accuracy down to micrometers – depending on the quality of the interfacing electronics

High reliability

Displacement < 1 m



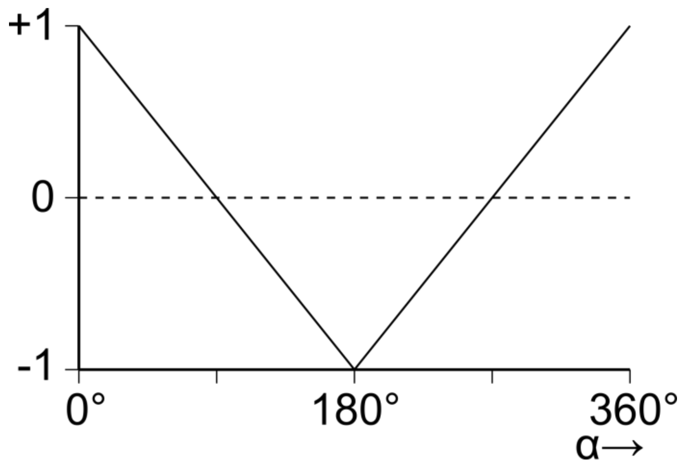
http://www.efunda.com/designstandards/sensors/lvdt/lvdt_theory.cfm

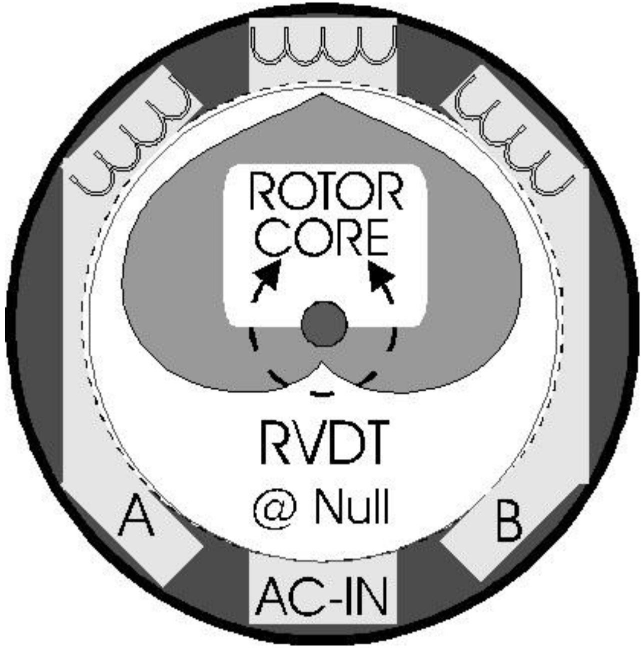


http://www.macrosensors.com/lvdt_tutorial.html

RVDT

Rotary Variable Differential Transformer





http://www.synchroconverters.com/rvdt.html

Incremental optical encoder

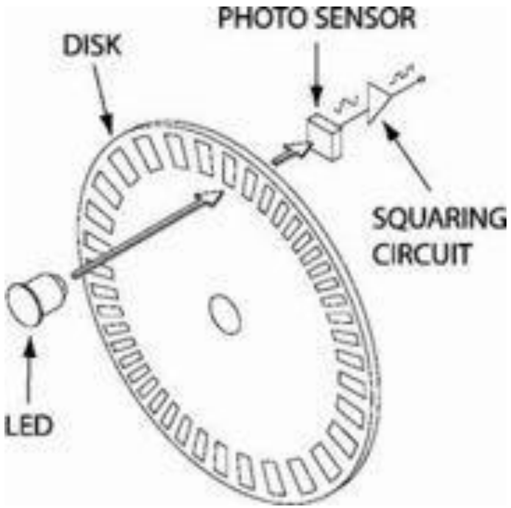
Measures change in angular position

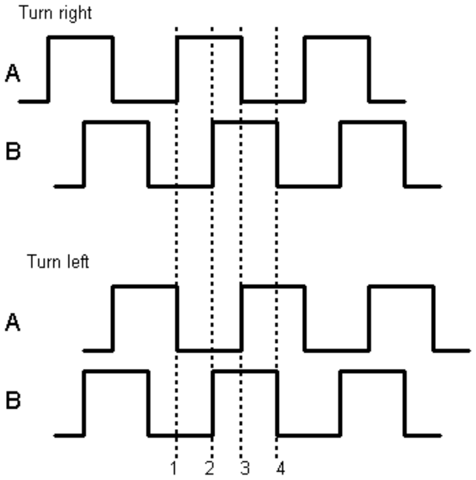
Simple design, good precision

Two signals with different phase

- Two detectors
- One ring with phase shifted detectors or two phase shifted rings

Quadrature encoding; Detect rising and falling edges from both signals





Absolute optical encoder

Several rings & detectors

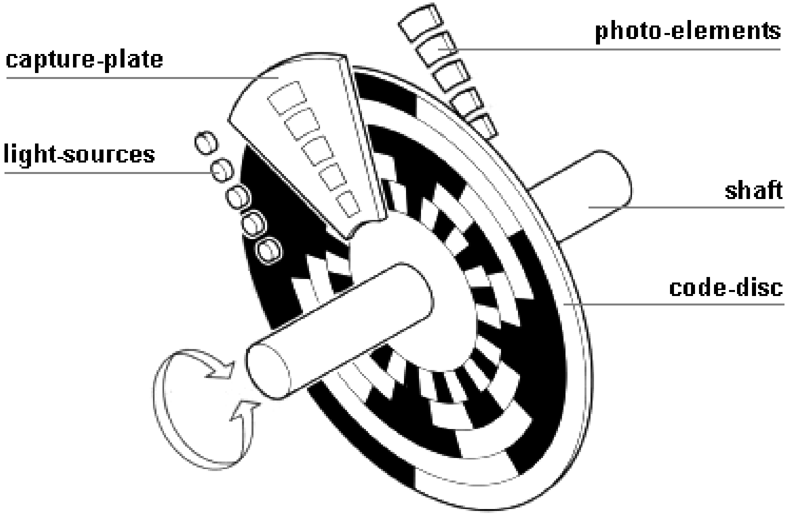
Unique signal combination for each angular position

- Number of possible angular positions 2^(number of rings)

Usually uses gray-coding instead of binary coding

- Only one bit at a time changes
- Smaller risk for errors

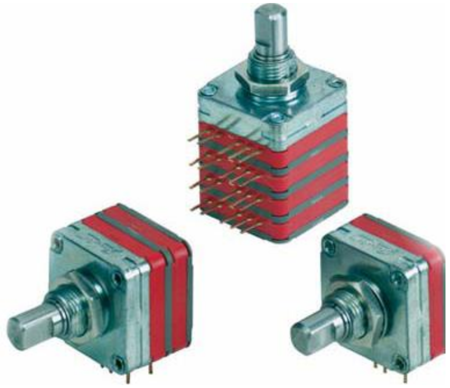
More complex design

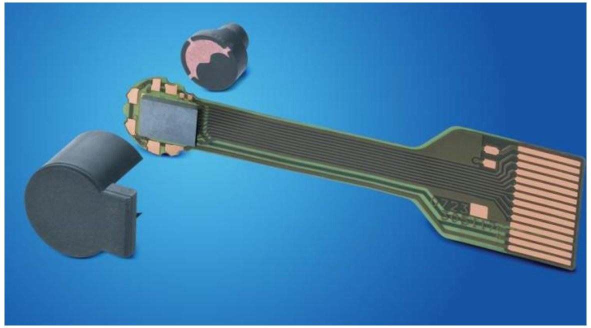


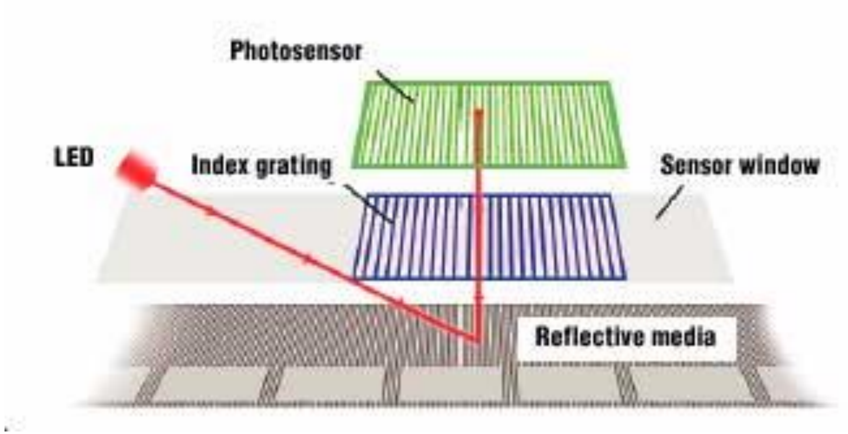
Other encoder types

Magnetic, inductive, mechanical…

Linear versions of incremental and absolute encoders





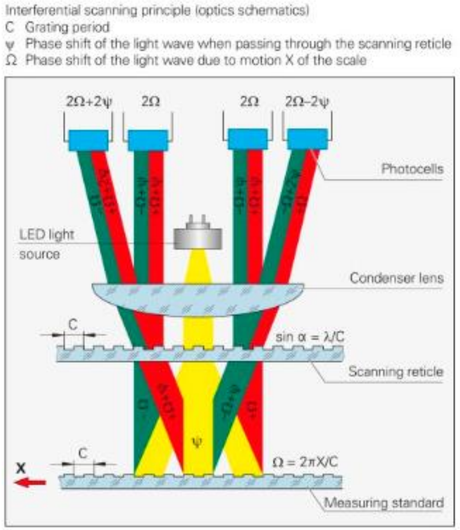


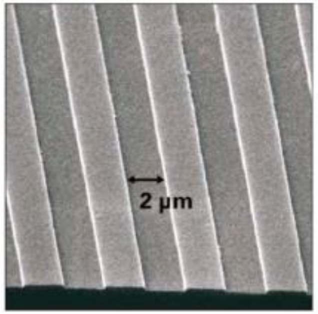
http://machinedesign.com/archive/when-go-linear

http://machinedesign.com/sensors/basics-rotary-encoders-overview-and-new-technologies-0

Precision linear encoder

Accuracies up to 0.1 µm





Old stuff: Resolver, synchro, tachogenerator

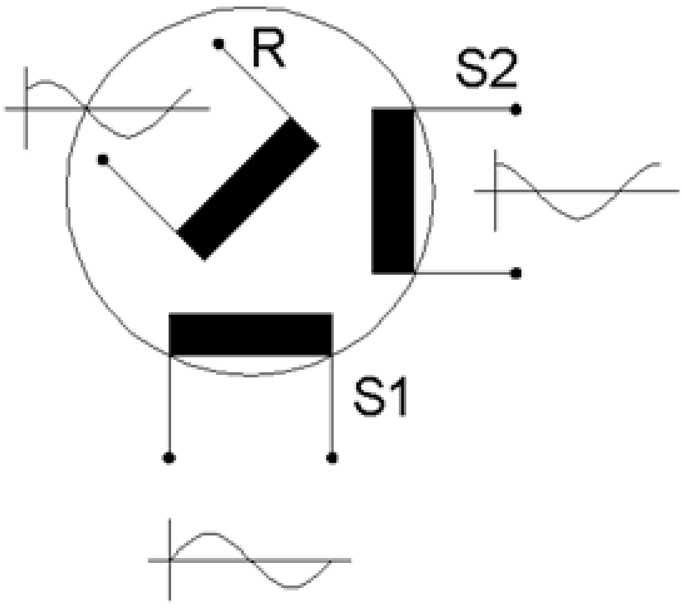
Resolver and synchro are analogue position sensors

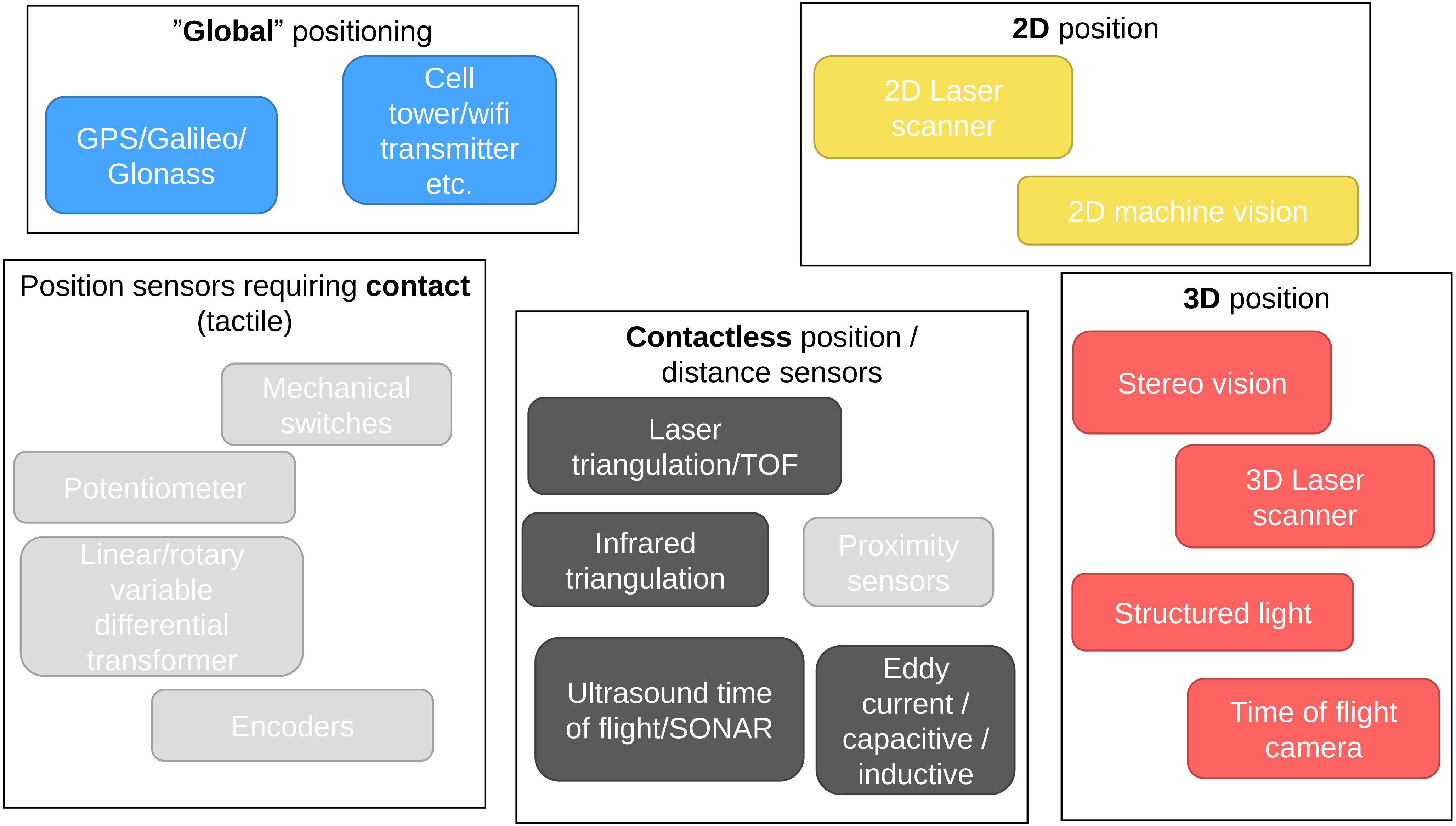
- AC excitation via transformer– AC output
- Reliable – no mechanical wear
- Multi-turn
- Very similar to RVDT

Tachogenerator is an analogue speed sensor

- ”inverted DC motor”

https://en.wikipedia.org/wiki/Resolver_%28electrical%29





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Time of flight camera

Proximity sensor

Binary switches (on/off)

- Change state when object is at a preset distance

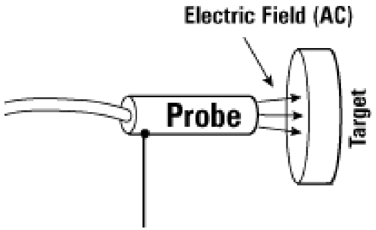
Range usually a couple of centimeters

Based on different mechanisms

- Optical
- Capacitive
- Inductive

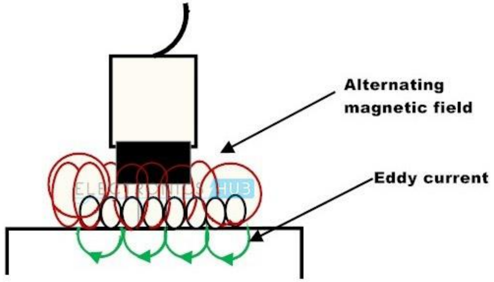
Proximity sensor example

Short range displacement sensors



Eddy current

- Range some millimeters, difficult environments

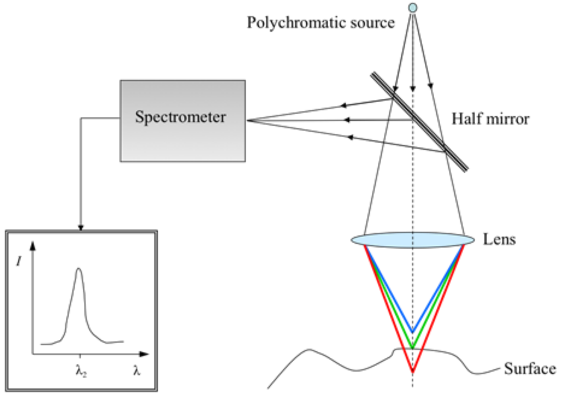


Capacitive

- Range some millimeters, only conductive targets
- Subnanometer resolution possible

White light

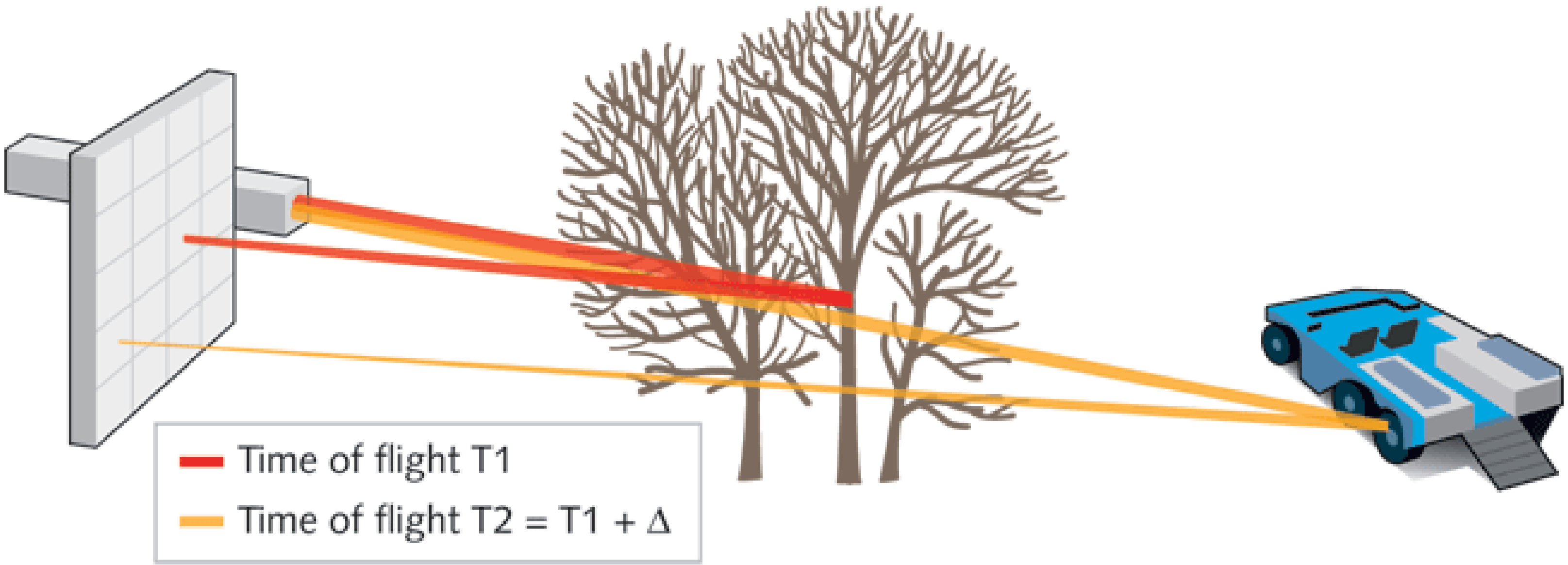
- Short range
- Very accurate, resolution down to nm
- Works also with glass



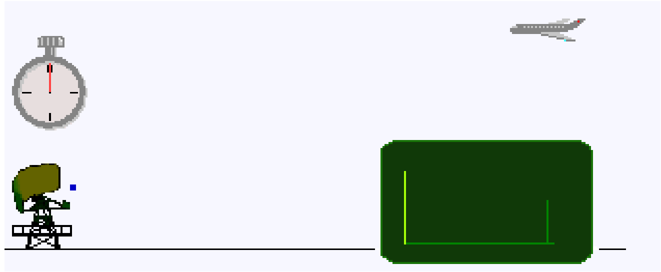
Time of flight principle

Distance derived from the time taken for a reflected beam to return

Multiple echos possible



Time of flight sensors

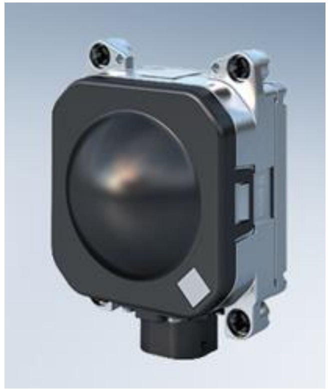


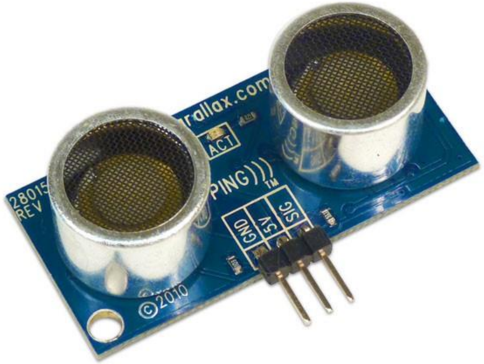
Radar (Radio detection and ranging)

Ultrasound

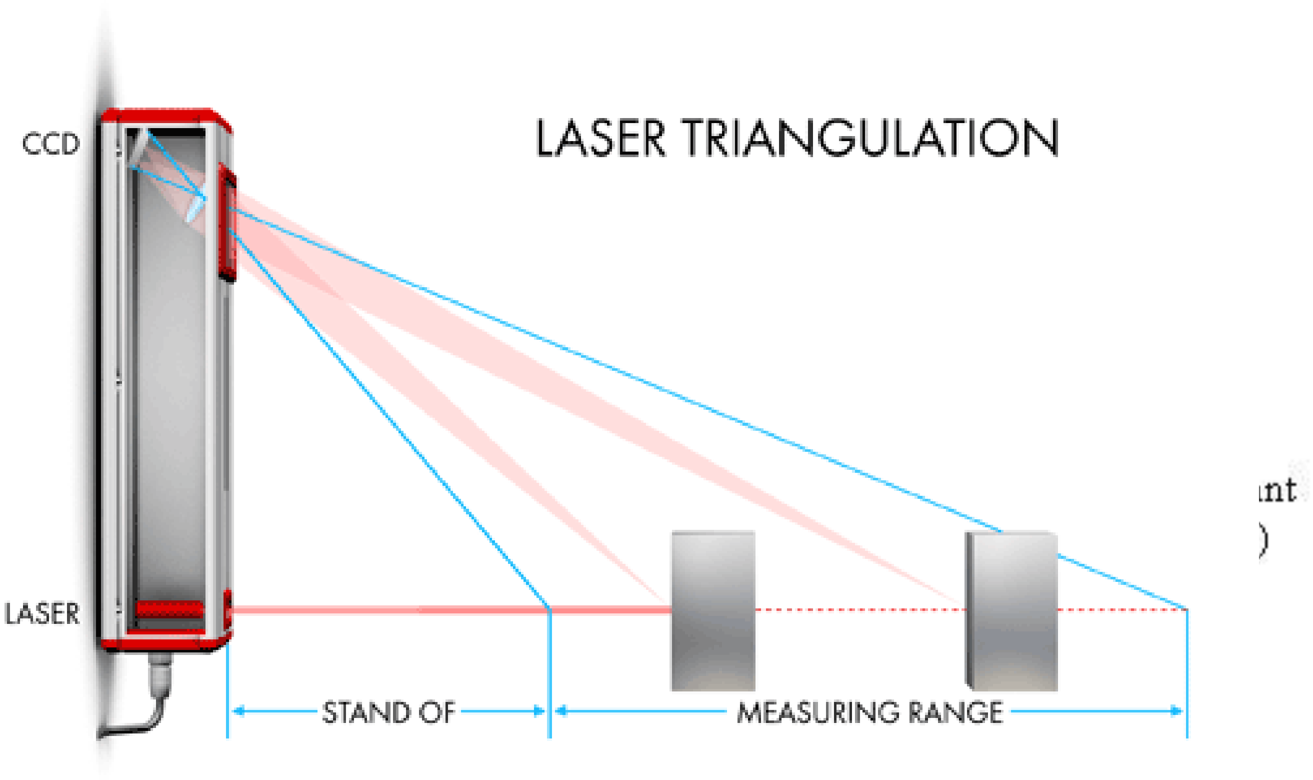
- Not very fast (cycle time ~50 ms)

Laser





Triangulation principle



https://www.lap-laser.com/metals-industries/products/ctg-ctlwg/measurement-principles/

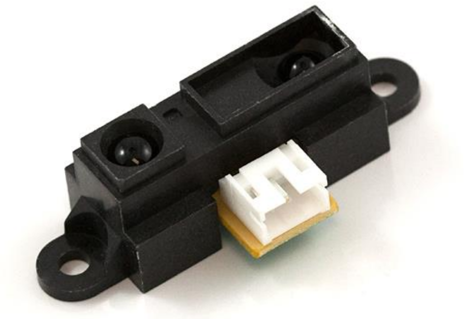
Triangulation sensors

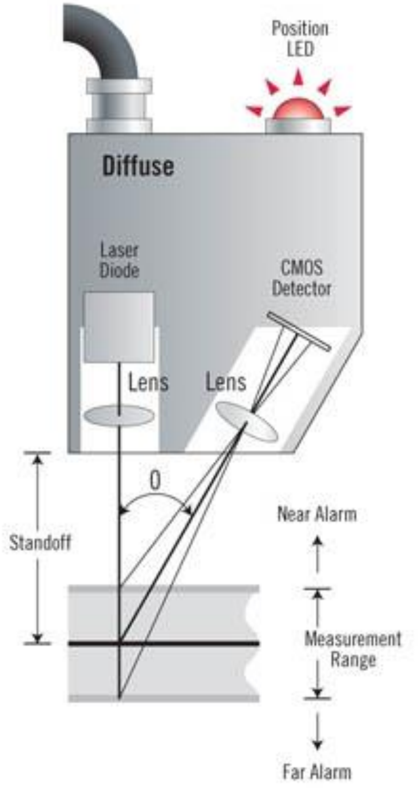
Laser triangulation

- very accurate, up to 0.01 μm

Infrared

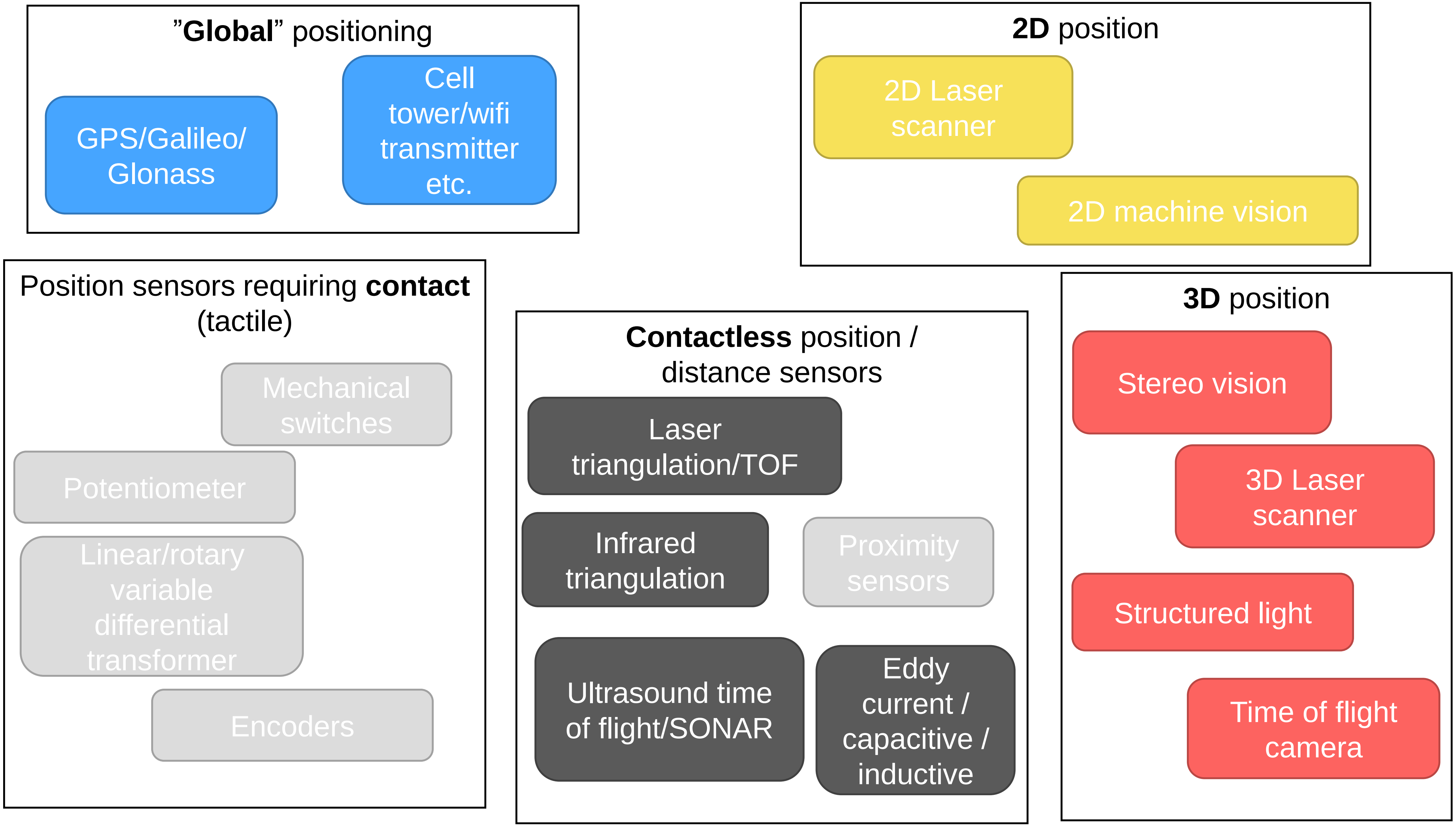
- Cheap ~20 euros
- Only for short distances (some meters)
- Can be disturbed by external light etc.





Lecture exercise

In small groups (2-4), discuss what kind of position sensors could be used in a robot vacuum cleaner.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Structured light
Time of flight camera

2D scanner

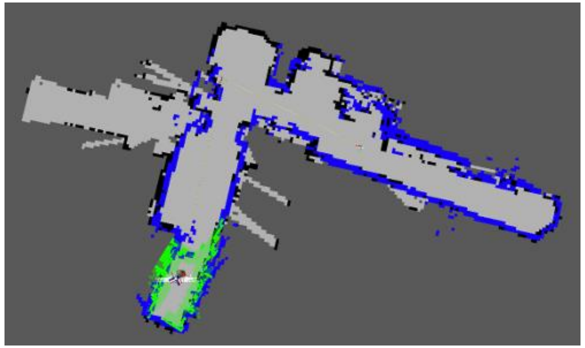
Rotating time of flight distance sensor

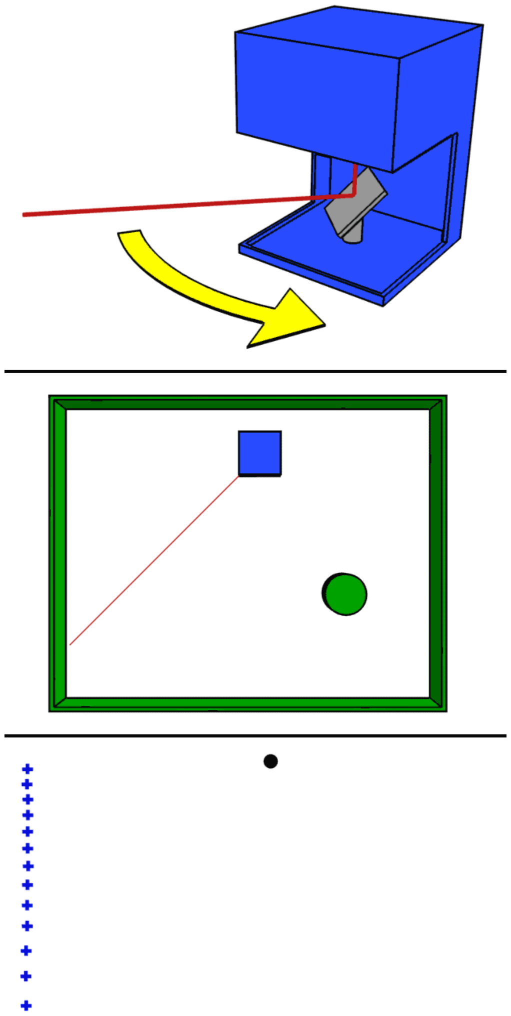
Laser (Lidar)

- Most used

Radar

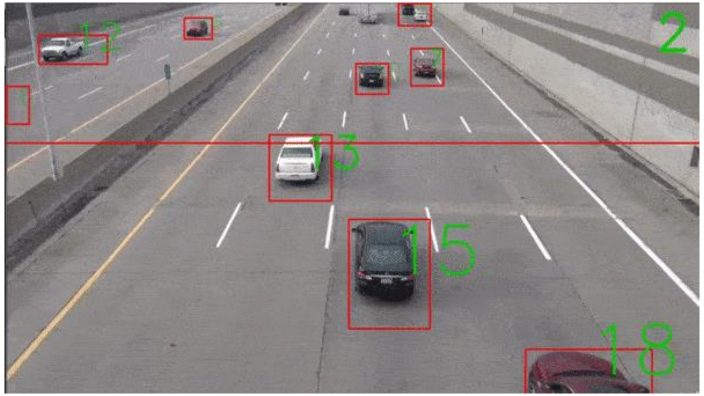
- More robust than laser
- Not as accurate
- No accurate functionality in one plane





A!

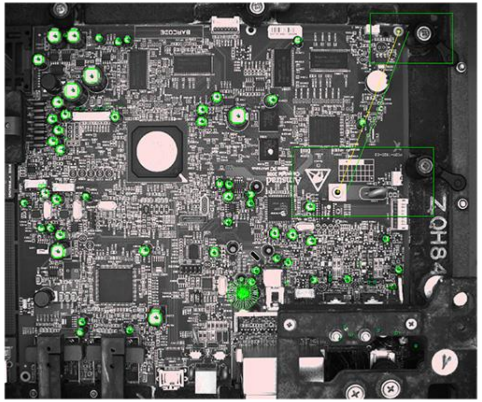
Machine Vision

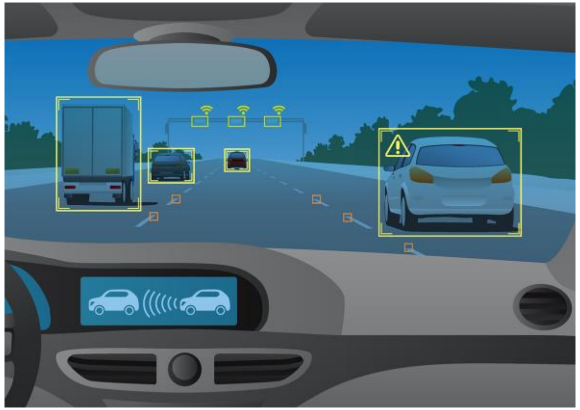


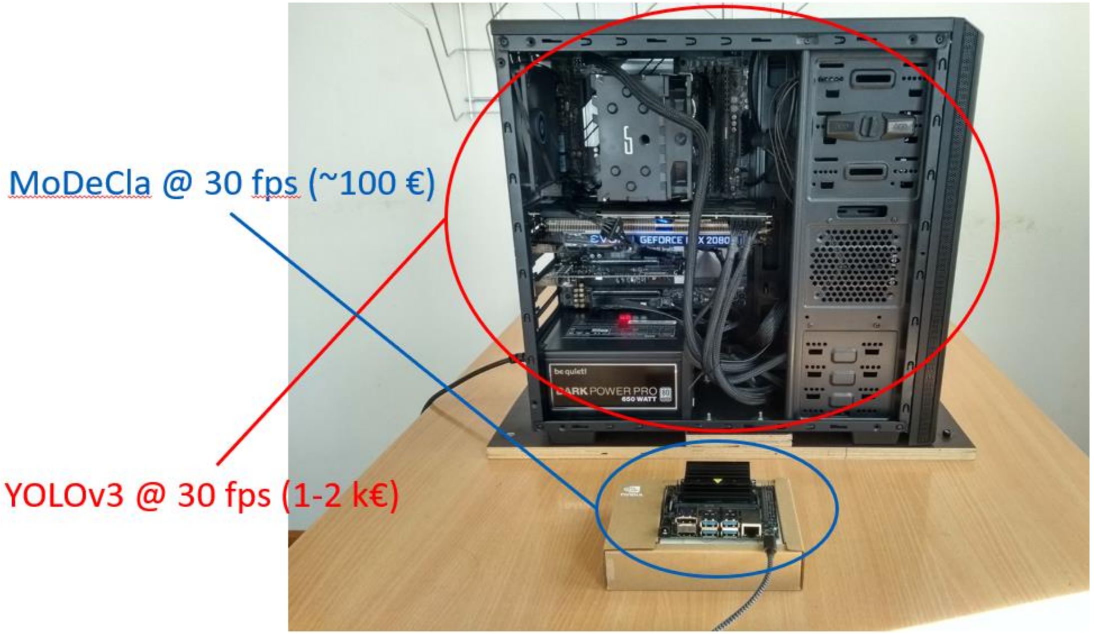
High accuracy possible

Low cost

Depends on computing power and algorithms

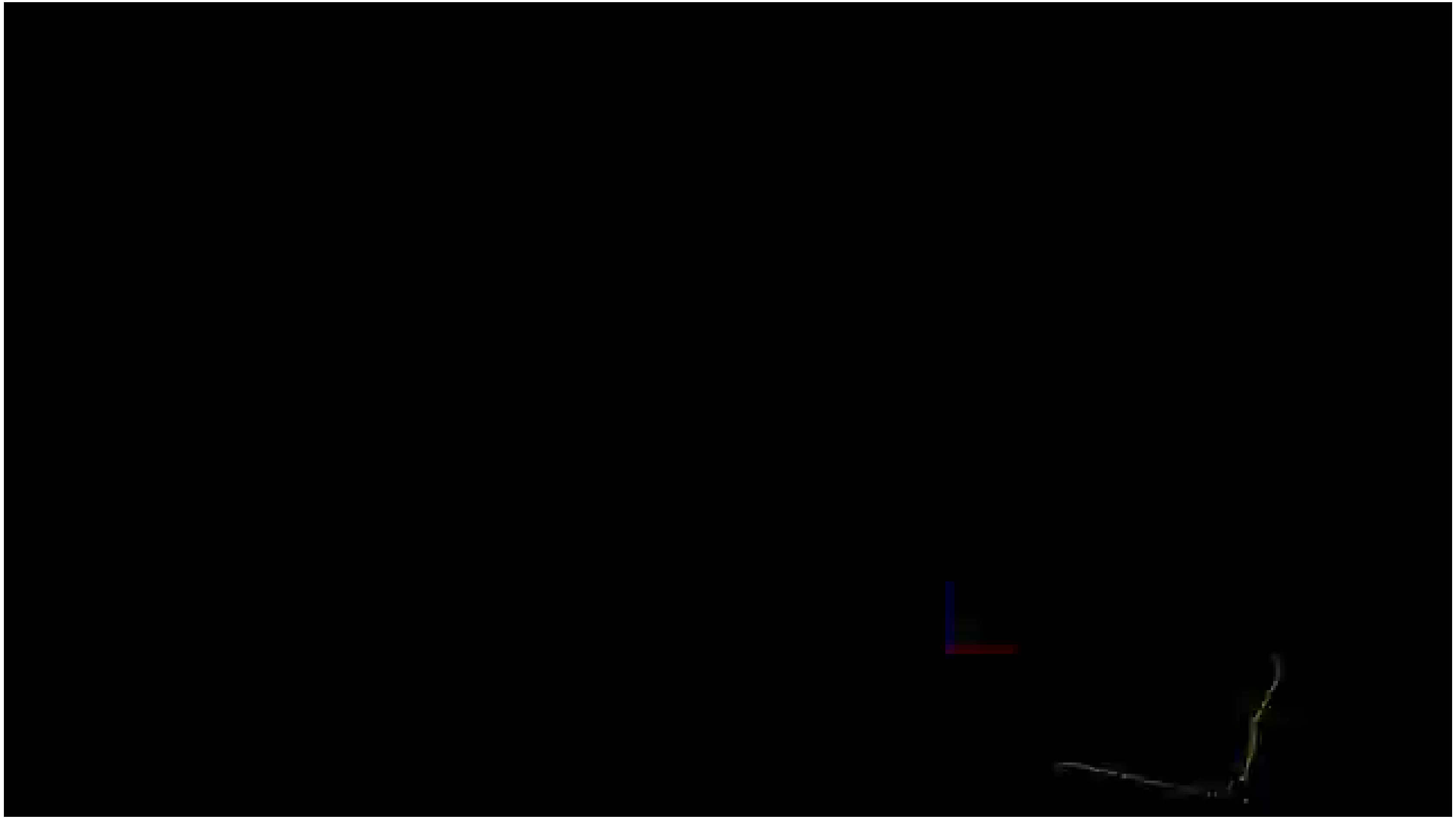




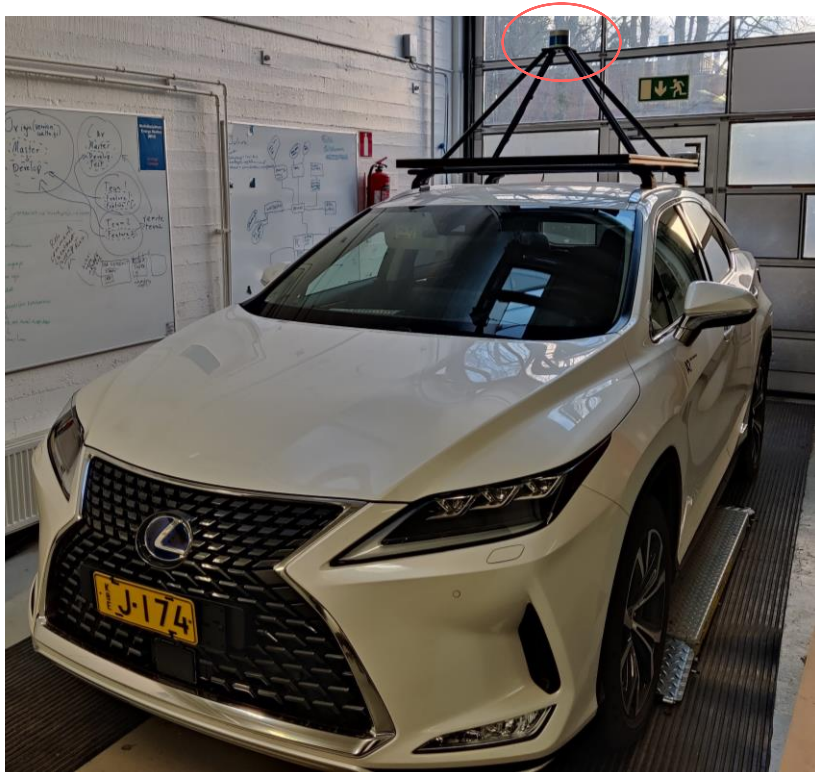

MoDeCla @ 30 fps (~100 €)
YOLOv3 @ 30 fps (1-2 k€)

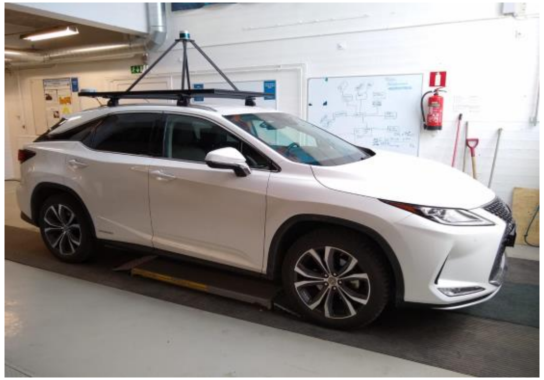
3D laser scanner (lidar)

3D laser scanner (lidar)



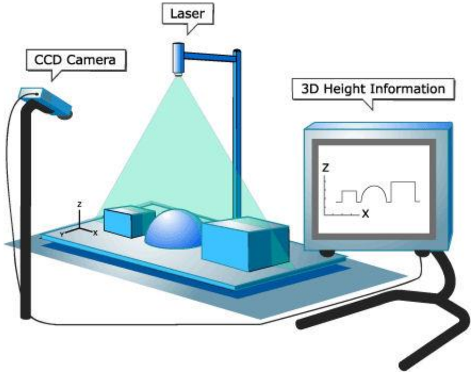
3D lidar





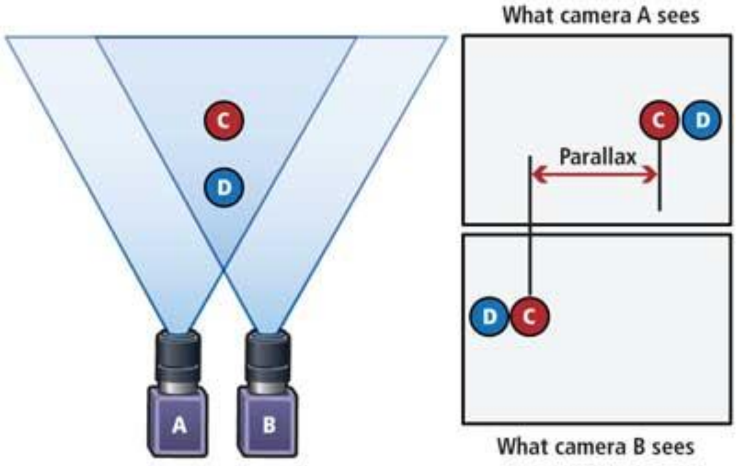
A!

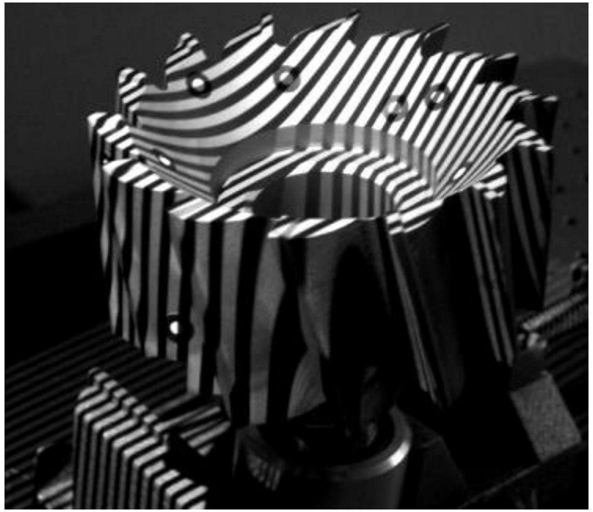
Stereo vision & structured light



Stereo vision = two cameras

Structured light = camera & projector

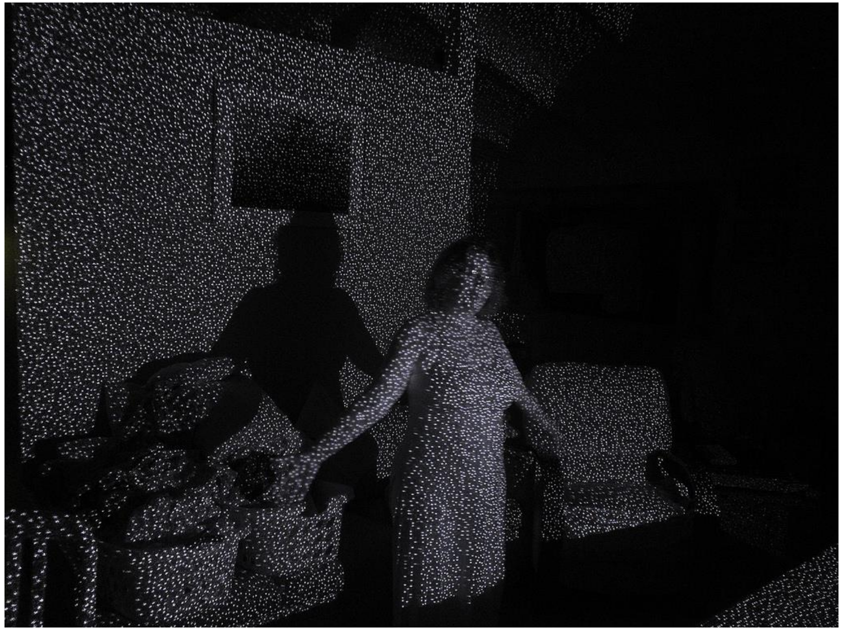


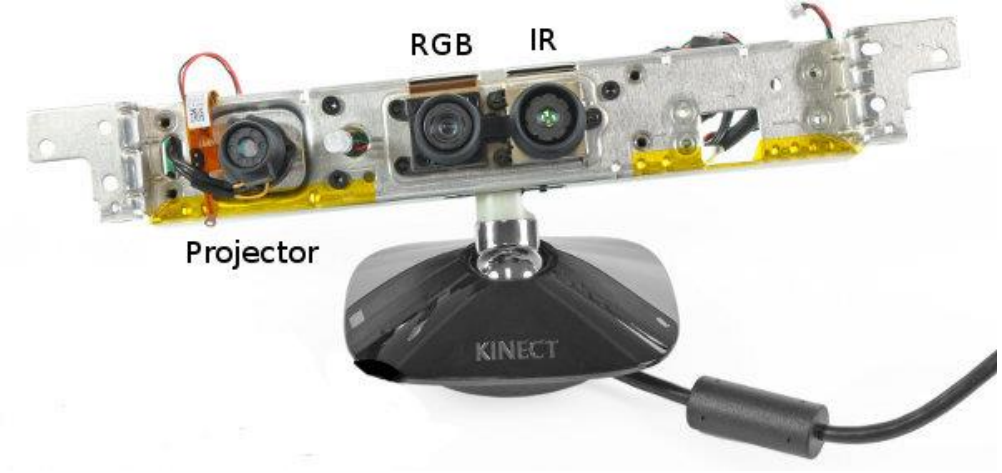


http://www.vision-systems.com/articles/print/volume-17/issue-4/departments/leading-edge-views/3-d-imaging-advances-capabilities-of-machine-vision-part-i.html

Kinect 1

Structured light

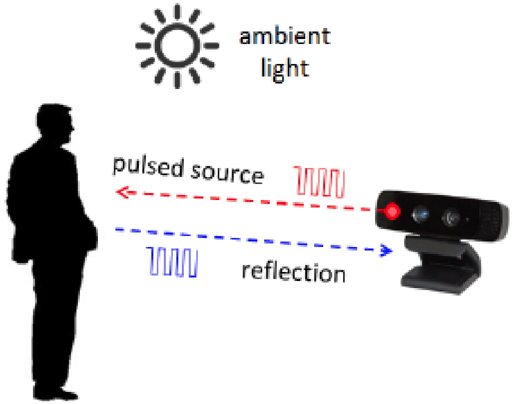


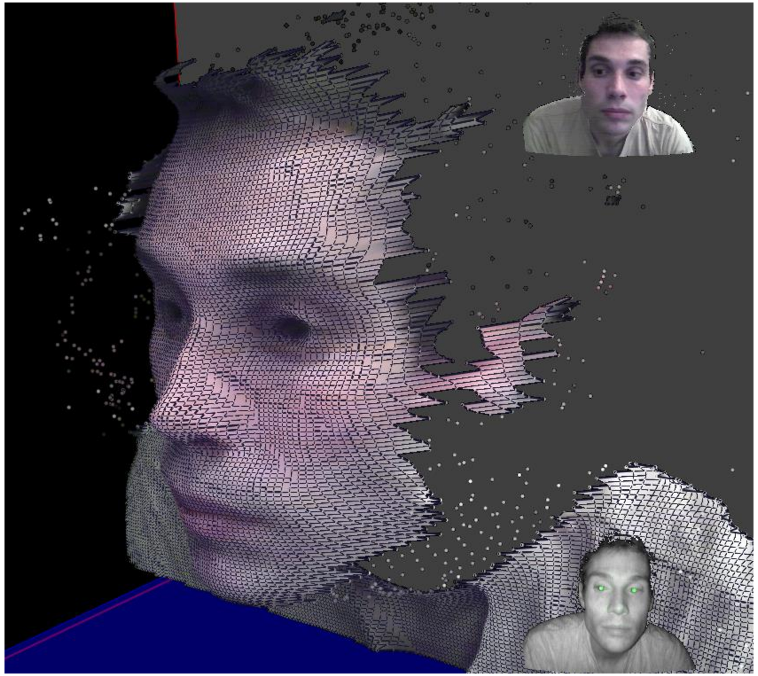


http://library.isr.ist.utl.pt/docs/roswiki/kinect_calibration(2f)technical.html

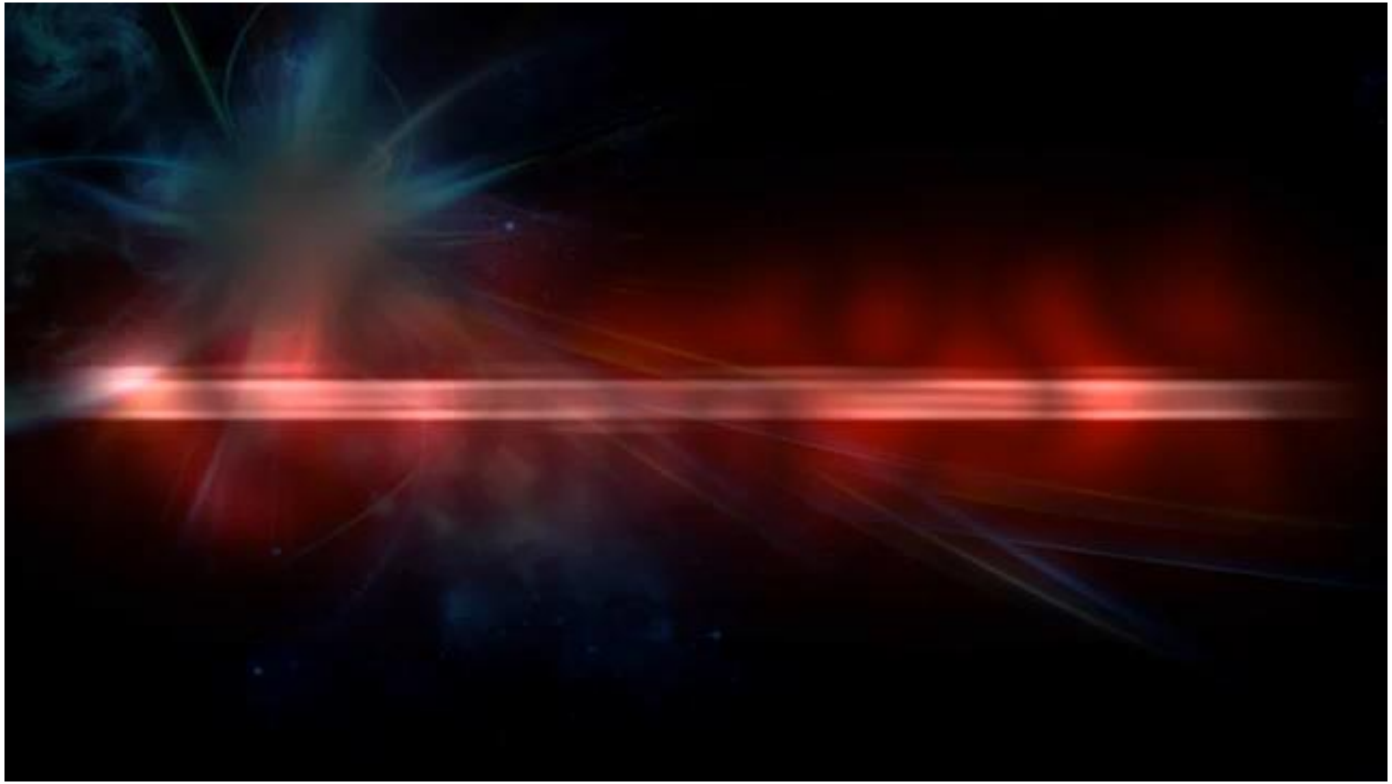
Kinect 2: Time-of-flight camera

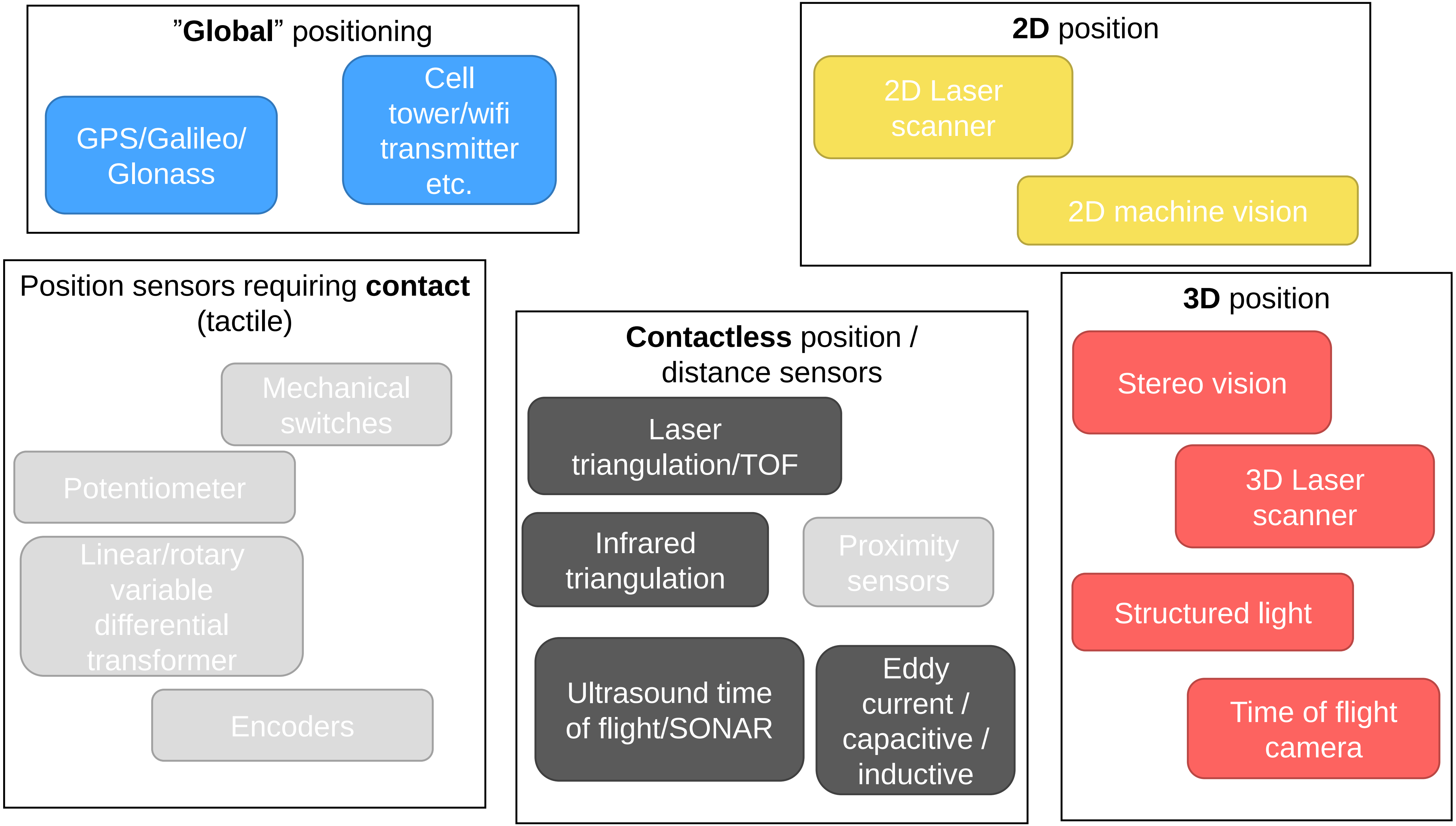
Simultaneous sampling
of distance to all pixels





3D simultaneous localization and mapping with TOF camera





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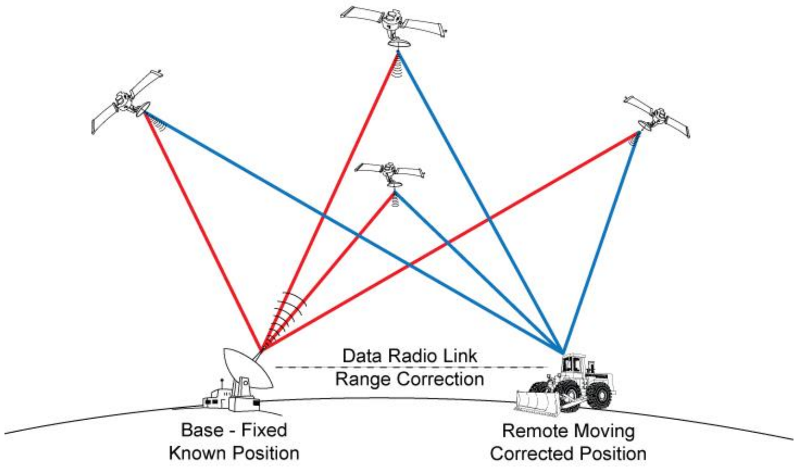
GPS



Global satellite positioning

- Not usable inside

Standard GPS

- accuracy <10 m

Differential GPS (DGPS)

- Accuracy from some meters to centimeters

Real Time Kinematic GPS (RTK GPS)

- Accuracy down to 1 cm, receivers (2 pcs) cost ~400€


326.5
G:326.9
I:175.8
8.5
OR


Panasonic
TOUGHBOOK
20.4
Direct

Other beacon positioning systems

Indoors

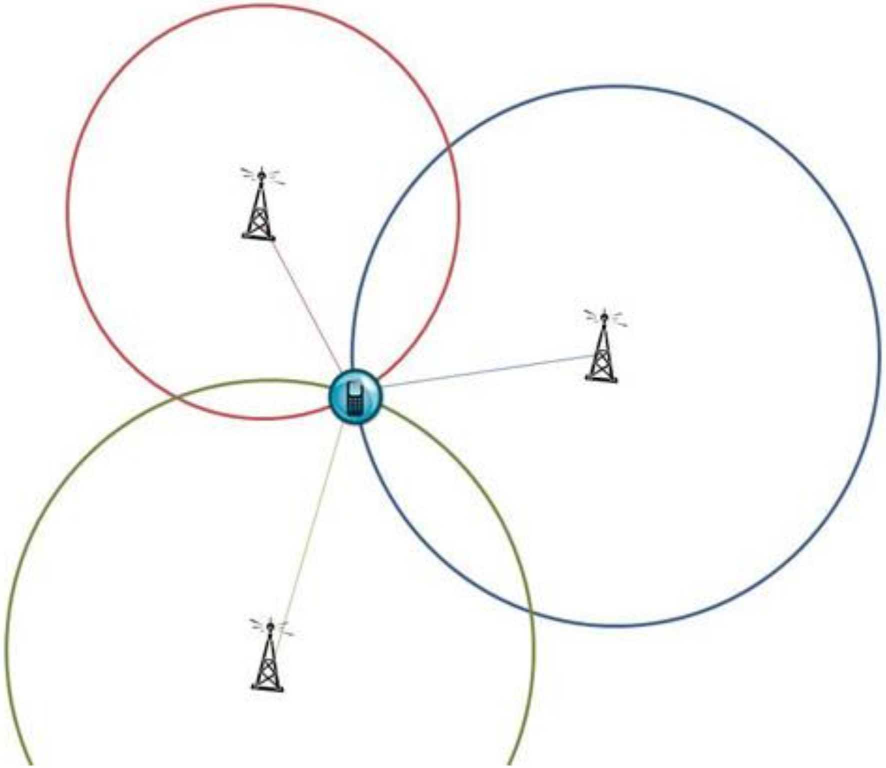
- Shopping centers
- Warehouses

Outdoors

- Between tall buildings where GPS struggles

Technologies

- Wifi
- Bluetooth
- Cell phone towers
- Dedicated beacons



Example: Tesla autopilot

GPS

- Global

Radar

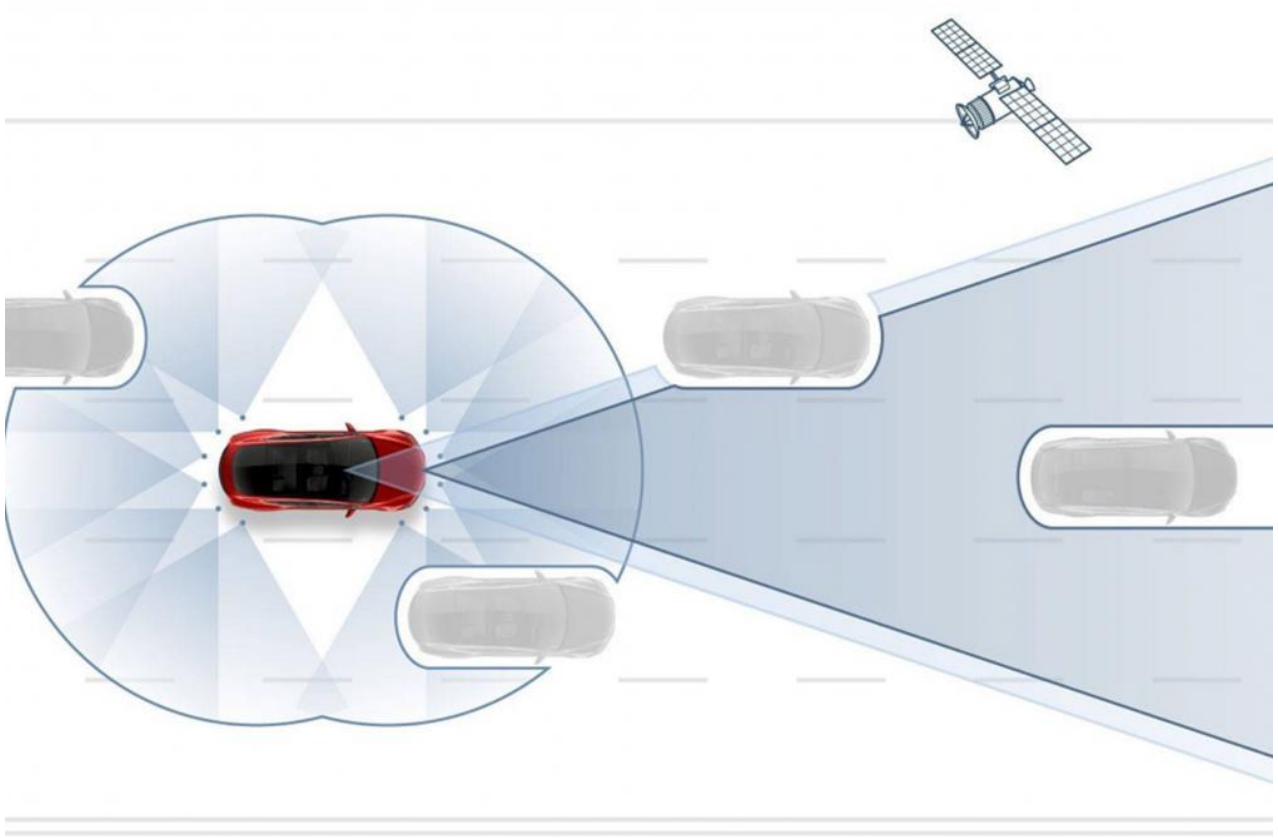
- Mid-range
- Only forward
- Robust

Camera

- Three views

Ultrasound

- Close range
- 360 °



http://www.evo.co.uk/tesla/model-s/16811/tesla-launches-autopilot-function-won-t-build-boring-autonomous-pods

Example: Tesla autonomous hardware

GPS

- Global

Radar

- Mid-range
- Only forward
- Robust

Camera

- 8 cameras, 360 °

Ultrasound

- Redundancy
- 360 °

https://electrek.co/2016/10/20/tesla-new-autopilot-hardware-suite-camera-nvidia-tesla-vision/

Aalto autonomous & mobility lab: A!ex

Sensors:

- 2x Mako G-319C cameras forward for stereo vision
- 1x Velodyne VLP32c lidar
- 1x Delphi ESR 2.5 24V radar
- 1x Novatel PwrPak7D-E2, RTK corrections available + 2x NovAtel 502 Low Profile Dual-frequency antennas GPS
- 1x IMU-IGM-S1/STIM300 inertial measurement unit

A!

My Volvo autopilot

General considerations

Absolute or incremental position

Disturbance to process from a mechanical contact

- Possible wearing

Sensitivity to external disturbances

- Temperature
- Sunlight
- Dirt, water, impacts

Accuracy vs. price

Sensor fusion

Comparison of position sensors

	Accuracy	Range	Reliability	Price
Laser	+++	0,001 m ->	++	€€-€€€
Ultrasound	+	0,1 - 10 m	++	€
Infrared	+	0,1 - 5 m	+	€
LVDT	++	0,01 - 1 m	+++	€€
Potentiometer	+	0,01 - 1 m	++	€ - €€
Optical encoder	+++	<- 10 m	++	€€
GPS	+	1 m->	++	€

Warning! Contains rough generalizations.