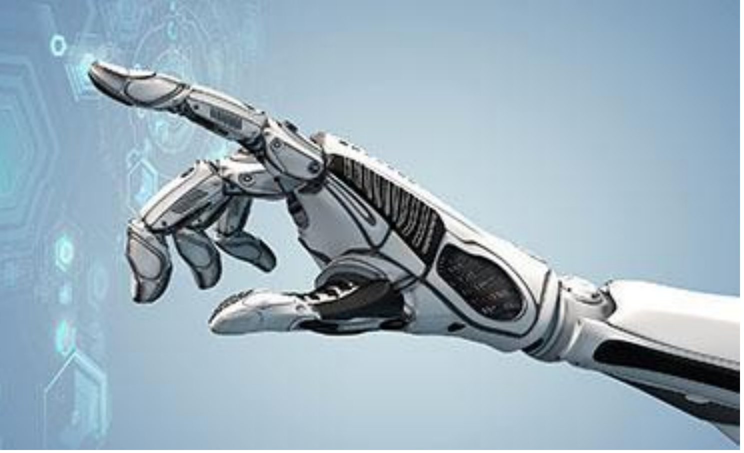


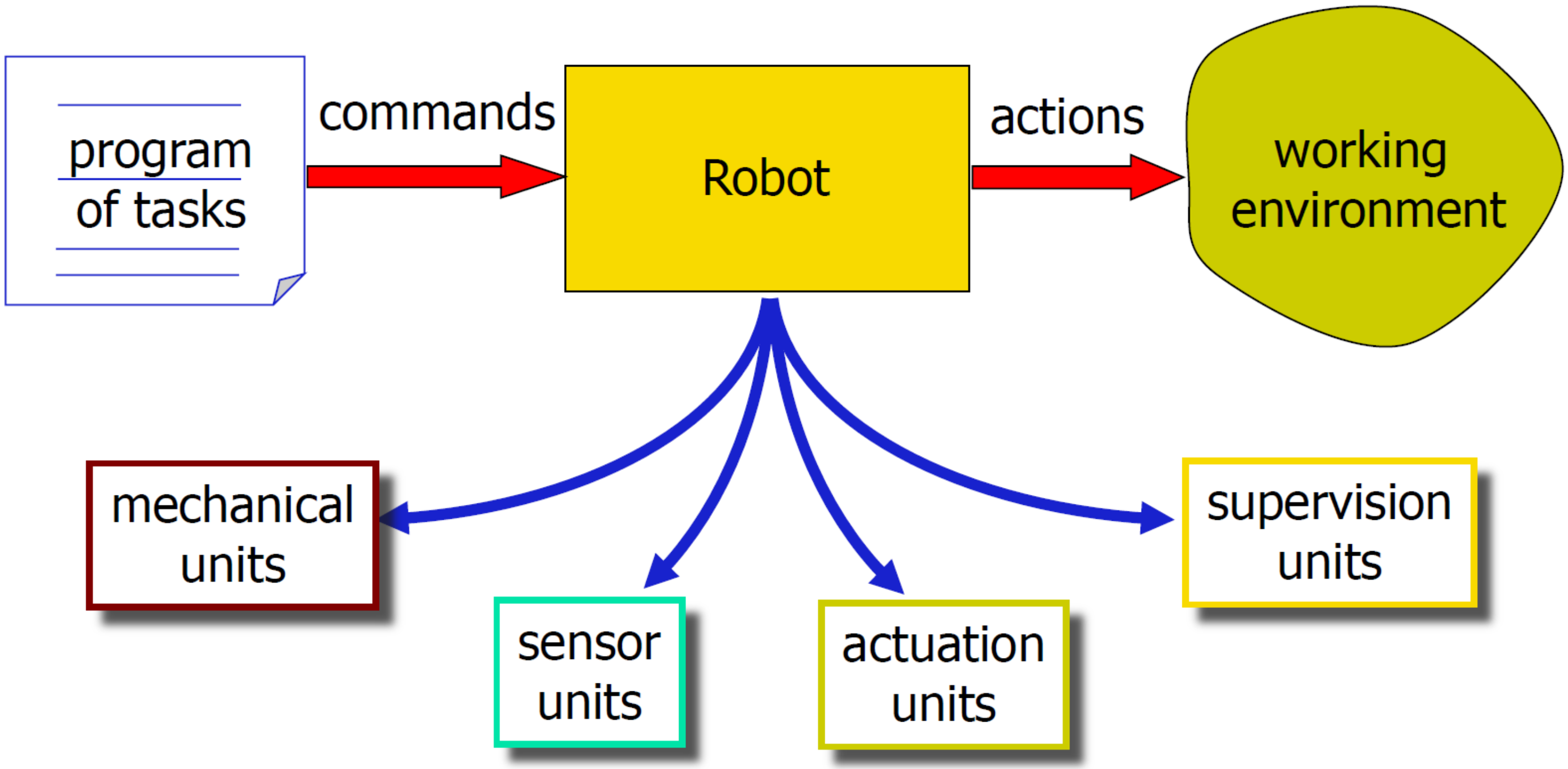
CSE444: Introduction to Robotics
Lesson 5a: Working with Sensors

ALL Follows
Summer 2019

Discussion Topics

- force sensors
  - strain gauges and joint torque sensor
  - 6D force/torque (F/T) sensor at robot wrist
  - RCC = Remote Center of Compliance *(not a sensor, but similar...)*
- proximity/distance sensors
  - infrared (IF)
  - ultrasound (US)
  - laser
  - with structured light
- vision
- examples of robot sensor equipments
- some videos intertwined, with applications

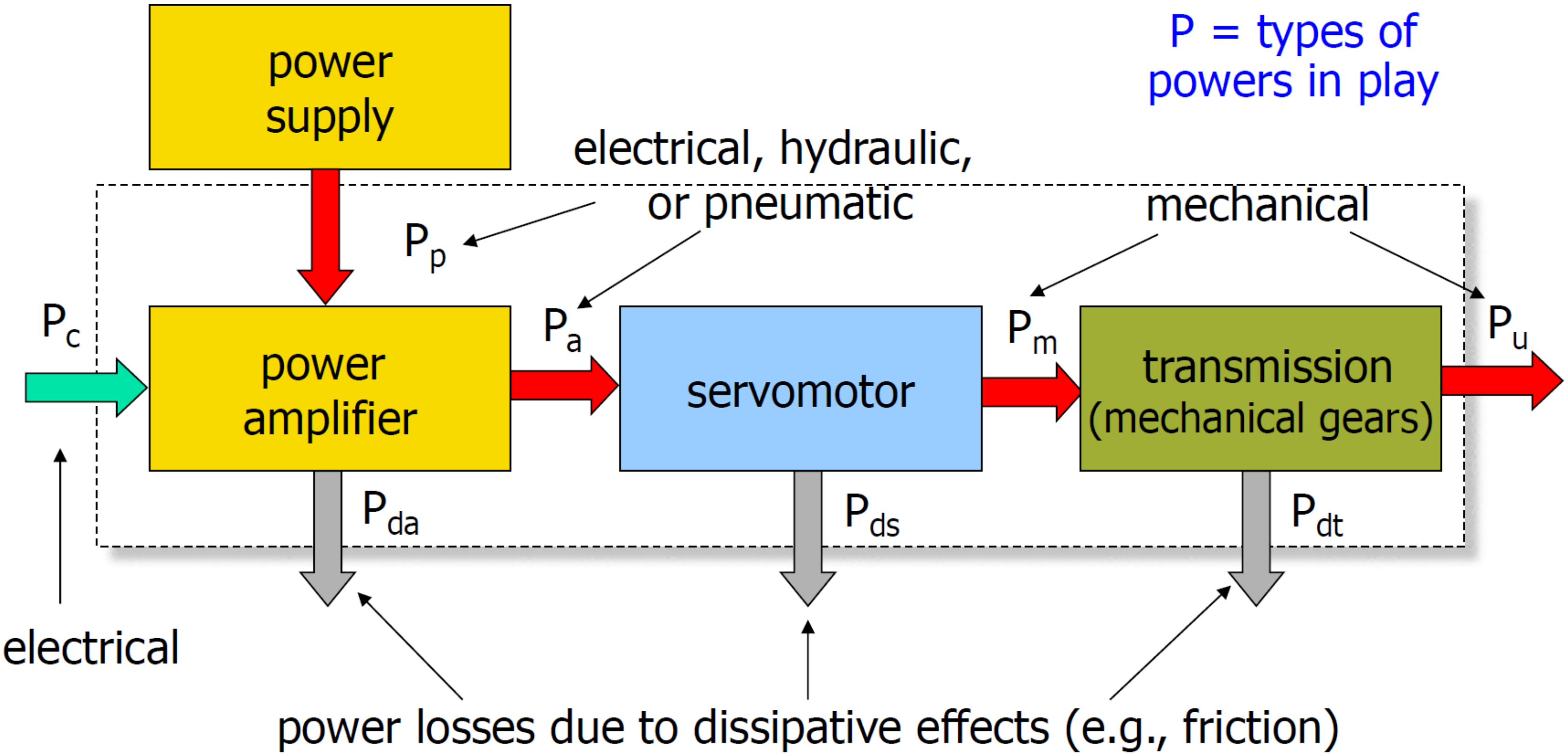
Robot as a System



Functional Unit of a Robot

- mechanical units (robot arms)
  - rigid links connected through *rotational* or *prismatic* joints (each 1 dof)
  - mechanical subdivisions:
    - *supporting structure* (mobility), *wrist* (dexterity), *end-effector* (task execution, e.g., manipulation)
- sensor units
  - proprioceptive (internal robot state: position and velocity of the joints)
  - exteroceptive (external world: force and proximity, vision, …)
- actuation units
  - motors (*electrical, hydraulic, pneumatic*)
  - motion control algorithms
- supervision units
  - task planning and control
  - artificial intelligence and reasoning

Actuation Systems



power = force · speed = torque · angular speed [Nm/s, W]

efficiency = power out / power in [%]

Properties of Measurement System

- accuracy

  agreement of measured values with a given reference standard (e.g., ideal characteristics)

- repeatability

  capability of reproducing as output similar measured values over consecutive measurements of the same constant input quantity

- stability

  capability of keeping the same measuring characteristics over time/temperature (similar to accuracy, but in the long run)

Accuracy and Repeatability in Robotics

- accuracy is how close a robot can come to a given point in its workspace
  - depends on machining accuracy in construction/assembly of the robot, flexibility effects of the links, gear backlash, payload changes, round-off errors in control computations, ...
  - can be improved by (kinematic) **calibration**
- repeatability is how close a robot can return to a previously taught point
  - depends only the robot controller/measurement resolution

video

- both may vary in different areas of the robot workspace
  - standard ISO 9283 defines conditions for assessing robot performance
  - limited to static situations (recently, interest also in dynamic motion)
  - robot manufacturers usually provide only data on "repeatability"

simple test on repeatability of a
Fanuc ArcMate100i robot (1.3 m reach)

Properties of Measurement System

- linearity error

  maximum deviation of the measured output from the straight line that best fits the real characteristics

  - as % of the output (measurement) range

- offset error

  value of the measured output for zero input

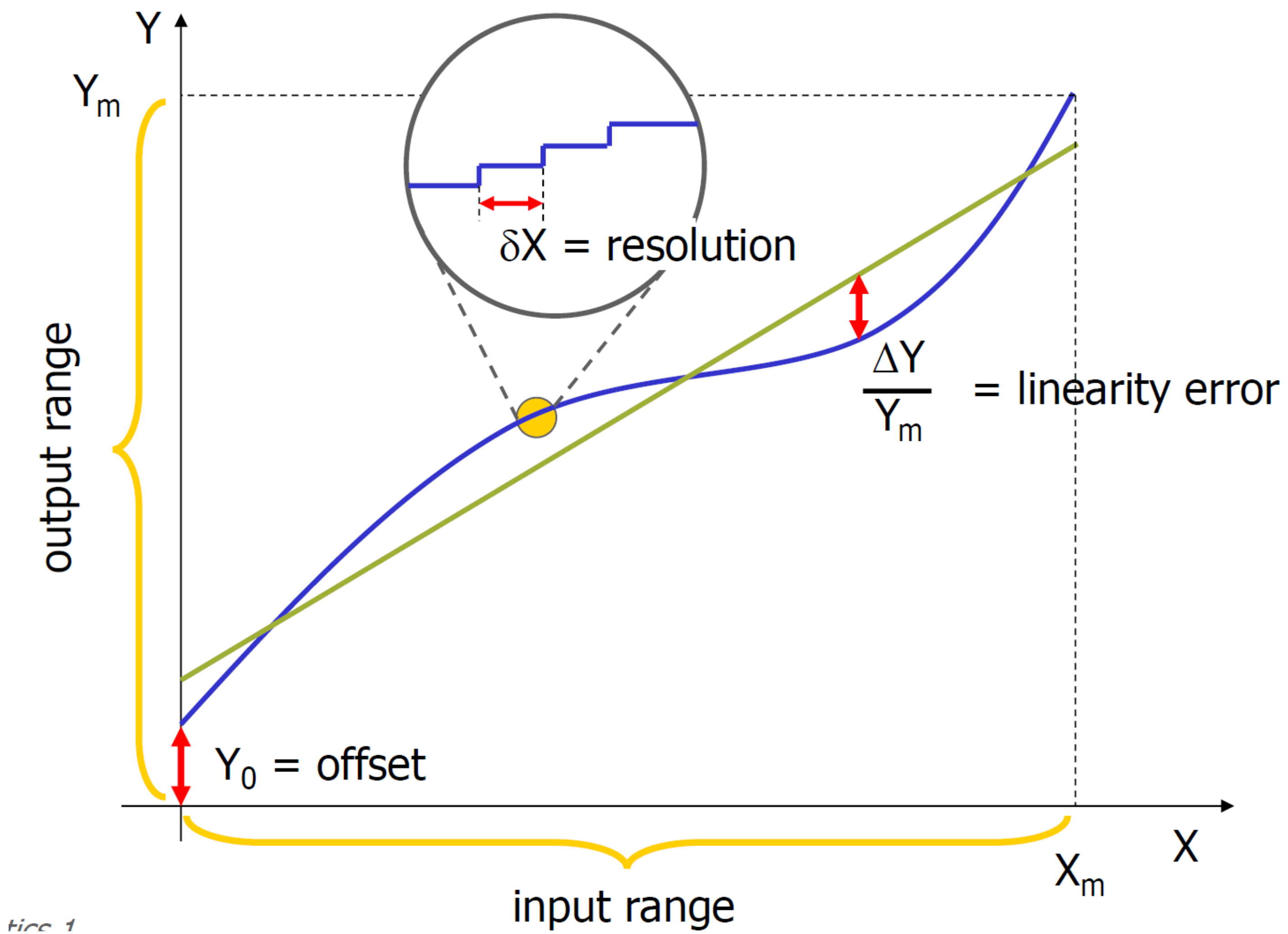
  - sometimes not zero after an operation cycle, due to hysteresis

- resolution error

  maximum variation of the input quantity producing no variation of the measured output

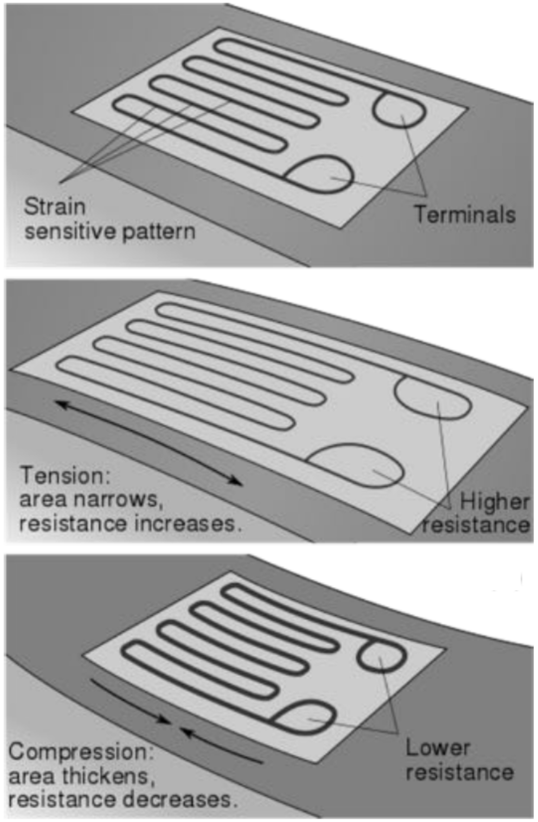
  - in absolute value or in % of the input range

Linearity, Offset and Resolution



Force/Torque and Deformation

- indirect information obtained from the measure of deformation of an elastic element subject to the force or torque to be measured
- basic component is a *strain gauge*: uses the variation of the resistance R of a metal conductor when its length L or cross-section S vary



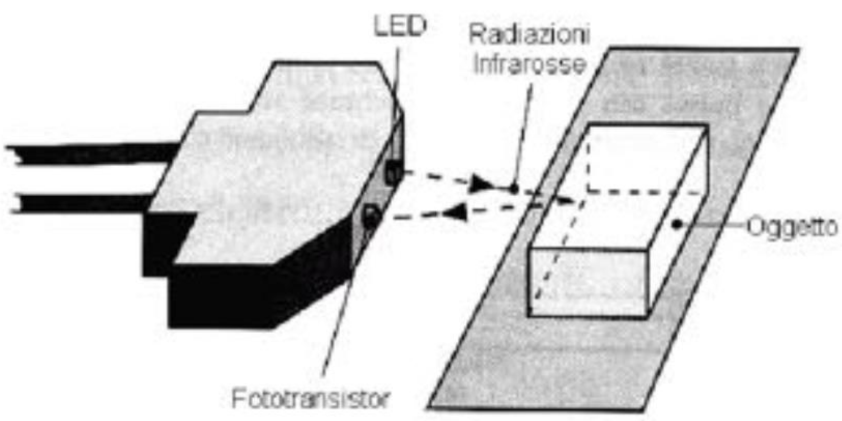
$$\frac{\partial R}{\partial L} > 0 \qquad \frac{\partial R}{\partial S} < 0$$

$$\frac{\partial R}{\partial T} \text{ small}$$

T ← temperature

Proximity/Distance Sensor

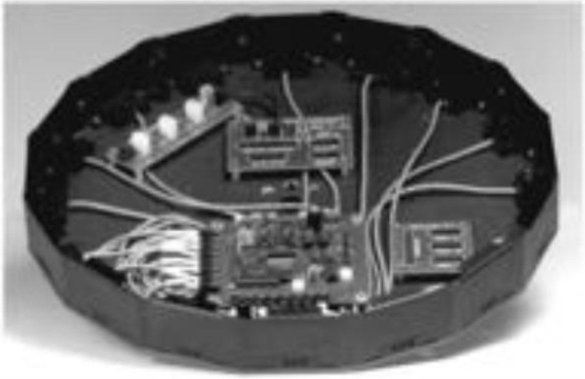
- infrared: a light source (LED) emitting a ray beam (at 850±70 nm) which is then captured by a receiver (photo-transistor), after reflection by an object
- received intensity is related to distance
  - narrow emitting/receiving angle; use only indoor; reflectance varies with object color
- typical sensitive range: 4÷30 cm or 20÷150 cm
- cost: 15 €



IR sensor SHARP GP2
(supply 5V, range 10÷80 cm)

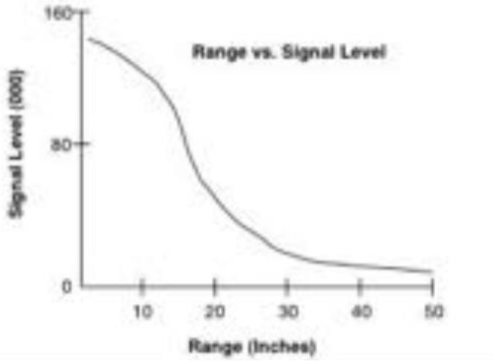
Infrared Sensor

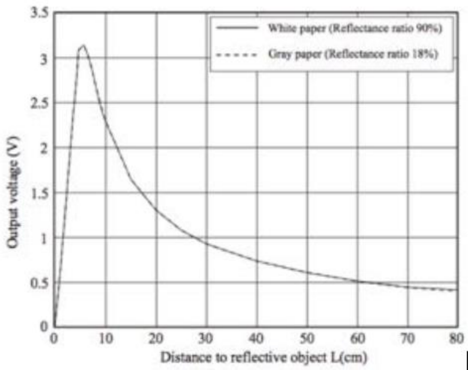
example: Sensus 300
on Nomad 200 mobile robot
(power data: 500 mA at 12 V)



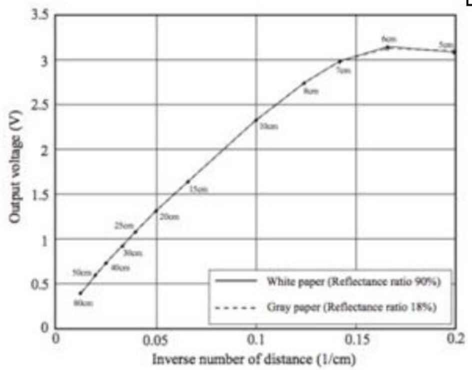
ring with 16 IR sensors

Sensus 300





Sharp GP2

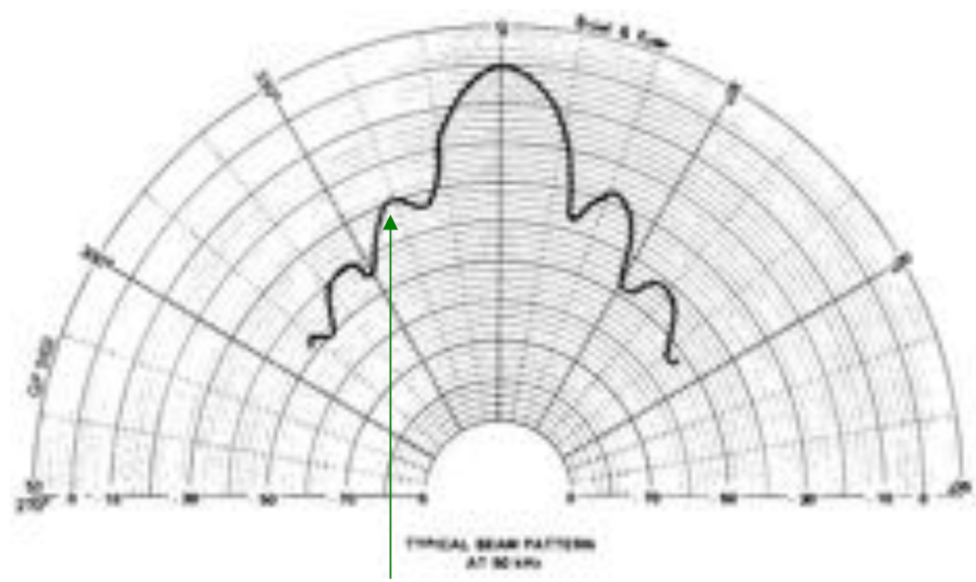


variation of received signal level as a direct or inverse function of distance

Proximity and Distance Sensor

- ultrasound: use of sound wave propagation and reflection (at > 20 kHz, mostly 50 kHz), generated by a piezoelectric transducer excited by alternate voltage ($V \sin \omega t$)
- distance is proportional to the Time-Of-Flight (TOF) along the sensor-object-sensor path

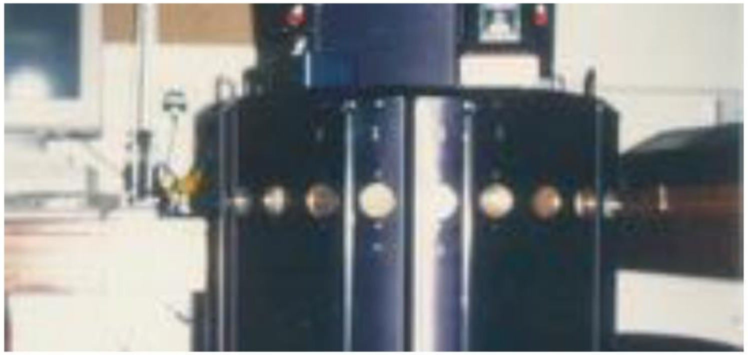
wave emitting angle $\approx 30^\circ$ allows to detect also obstacles located slightly aside from the front direction (but with uncertainty on their angular position)



energy lobes

Polaroid Ultrasound Sensor

- complete "kit" with trans-receiver and circuitry
- 3.5 ms of TOF for a front obstacle placed at 60 cm of distance
- range: 0.5÷2.5 m
- cost: < 30 €
- typical circular mounting of 16-32 US sensors (with a suitable sequence of activation)

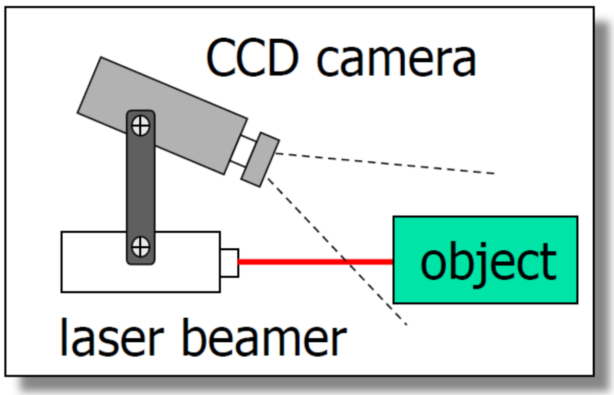


Polaroid USP3

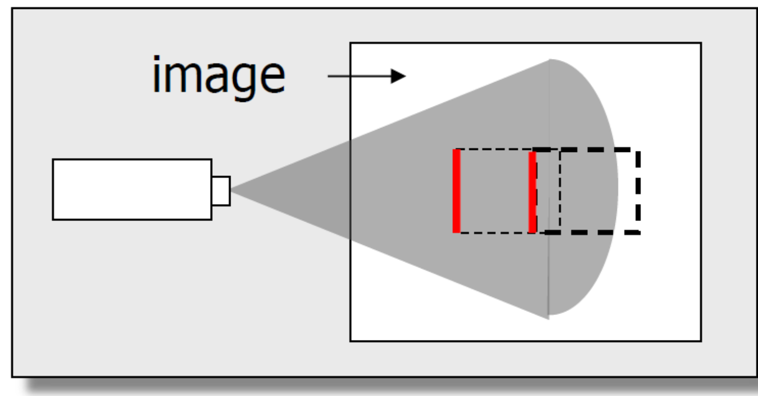
Migatron RPS 409

Proximity and Distance Sensors

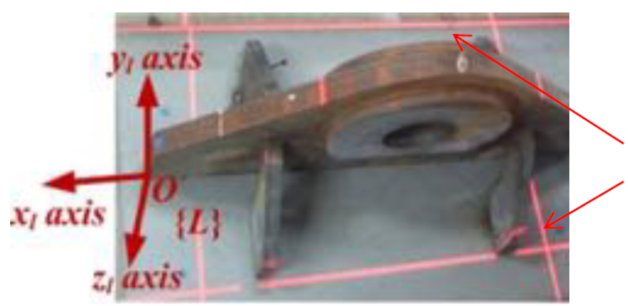
- structured light: a laser beam (coherent light source) is projected on the environment, and its planar intersection with surrounding objects is detected by a (tilted) camera
- the position of the "red pixels" on the camera image plane is in trigonometric relation with the object distance from the sensor



side view

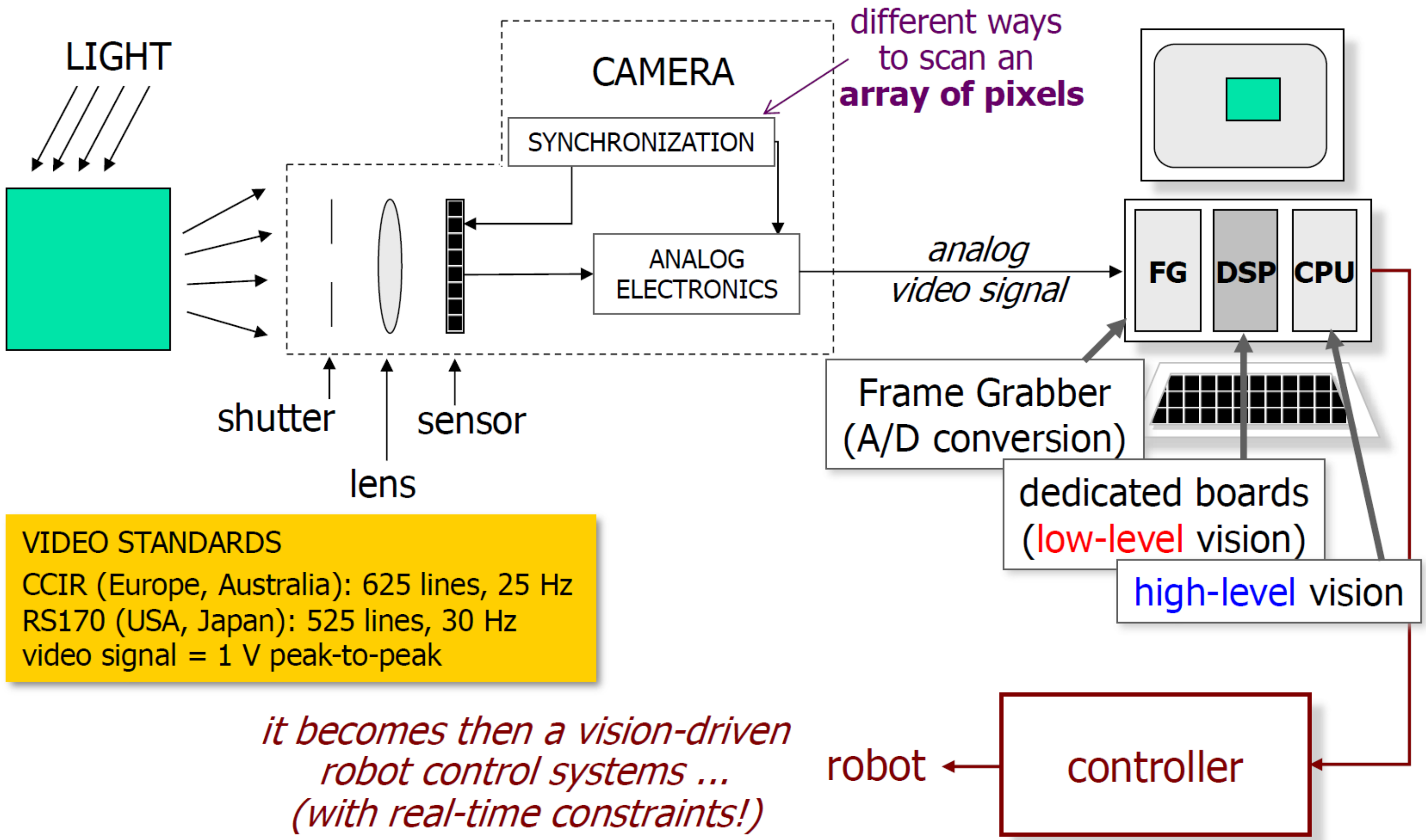


top view



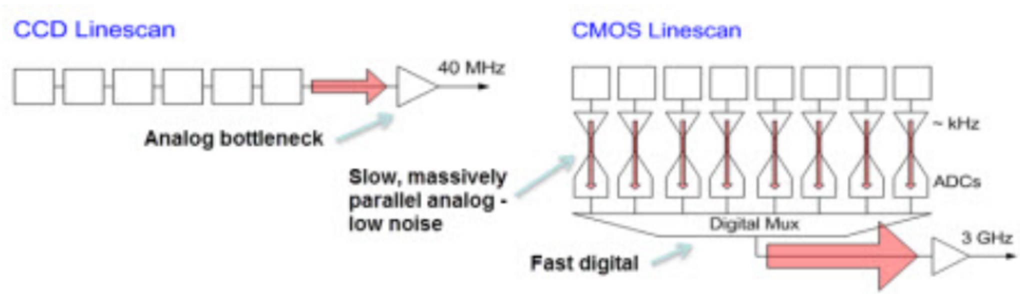
projected laser beams
(2D in this case)

Vision Systems



Sensors for Vision

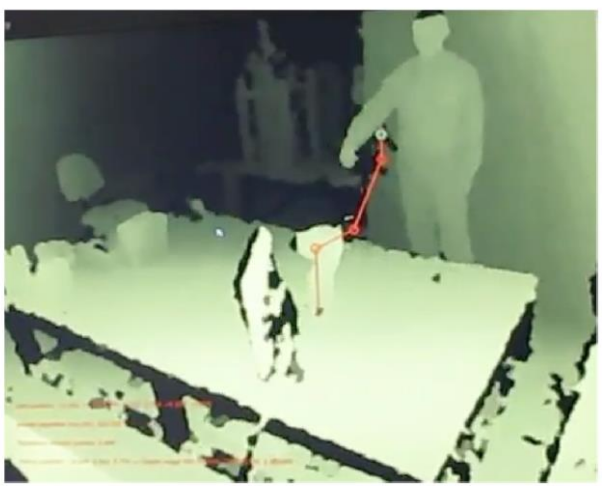
- arrays (spatial sampling) of photosensitive elements (pixel) converting light energy into electrical energy
- CCD (Charge Coupled Device): each pixel surface is made by a semiconductor device, accumulating free charge when hit by photons (photoelectric effect); "integrated" charges "read-out" by a sequential process (external circuitry) and transformed into voltage levels
- CMOS (Complementary Metal Oxide Semiconductor): each pixel is a photodiode, directly providing a voltage or current proportional to the instantaneous light intensity, with possibility of random access to each pixel



Kinect

camera+structured light 3D sensor

- RGB camera (with 640 × 480 pixel)
- depth sensor (by PrimeSense)
  - infrared laser emitter
  - infrared camera (with 320 × 240 pixel)
- 30 fps data rate
- range: 0.5÷5 m
- depth resolution: 1cm@2m; 7cm@5m
- cost: < 90 €



"skeleton" extraction and human motion tracking

Characteristics of Robot Servo Motor

- low inertia
- high power-to-weight ratio
- high acceleration capabilities
  - variable motion regime, with several stops and inversions
- large range of operational velocities
  - 1 to 2000 rpm (round per min)
- high accuracy in positioning
  - at least 1/1000 of a turn
- low torque ripple
  - continuous rotation at low speed
- power: 10W to 10 kW

Servomotors

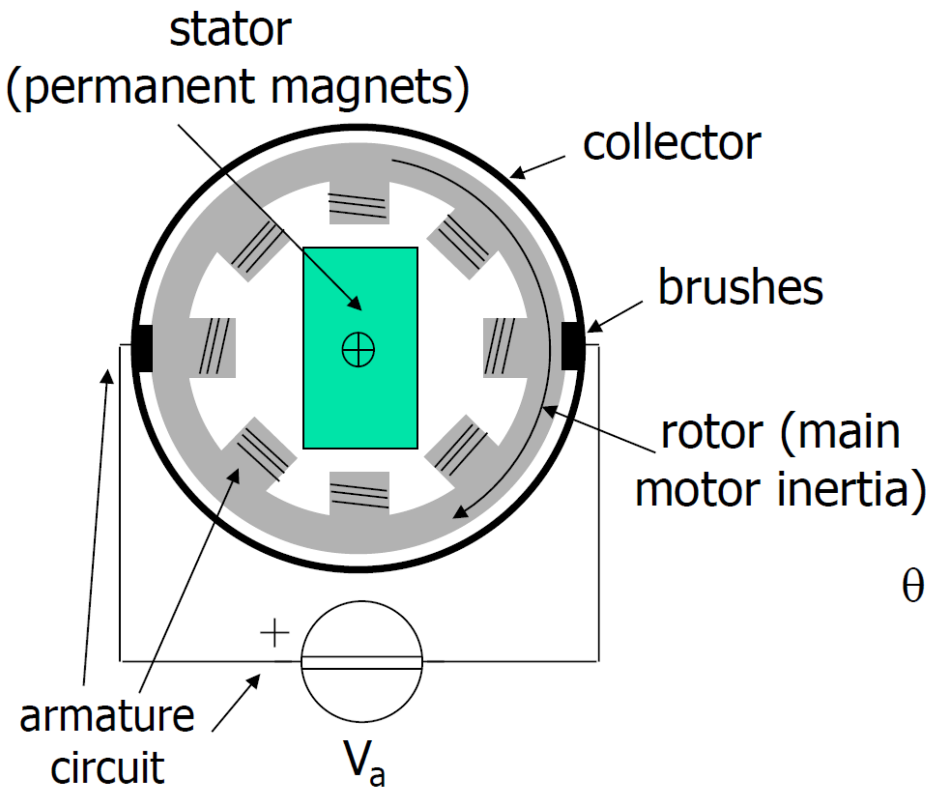
- pneumatic: pneumatic energy (compressor) → pistons or chambers → mechanical energy
  - difficult to control accurately (change of fluid compressibility) → no trajectory control
  - used for opening/closing grippers
  - ... or as artificial muscles (McKibben actuators)

- hydraulic: hydraulic energy (accumulation tank) → pumps/valves → mechanical energy
  - advantages: no static overheating, self-lubricated, inherently safe (no sparks), excellent power-to-weight ratio, large torques at low velocity (w/o reduction)
  - disadvantages: needs hydraulic supply, large size, linear motion only, low power conversion efficiency, high cost, increased maintenance (oil leaking)

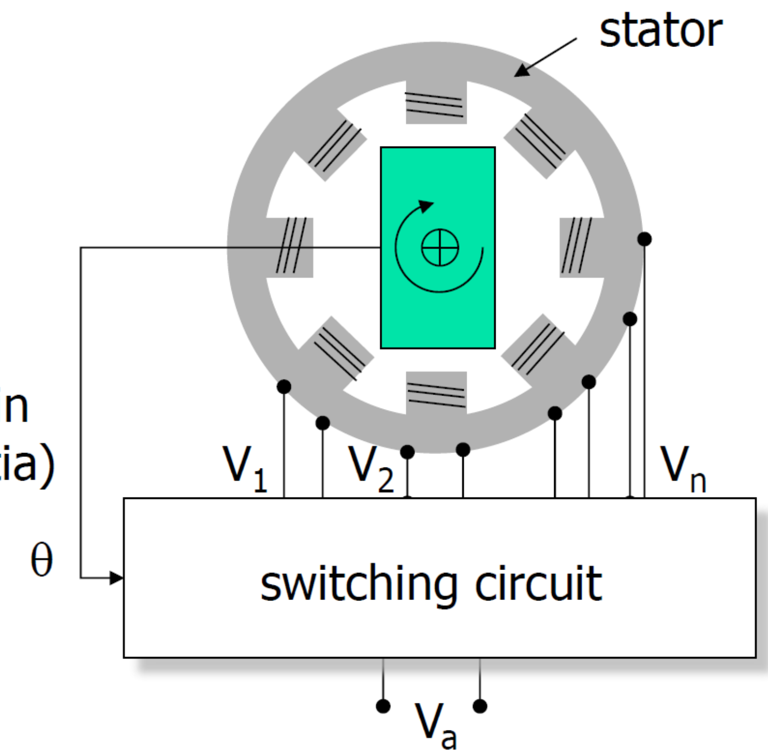
Electrical Servo Motors

- advantages
  - power supply available everywhere
  - low cost
  - large variety of products
  - high power conversion efficiency
  - easy maintenance
  - no pollution in working environment
- disadvantages
  - overheating in static conditions (in the presence of gravity)
    - use of emergency brakes
  - need special protection in flammable environments
  - some advanced models require more complex control laws

Electrical Servo Motors for Robots



direct current (DC) motor



with electronic switches (brushless)