Sensor 1&2 - Displacement and force sensors

ME490A

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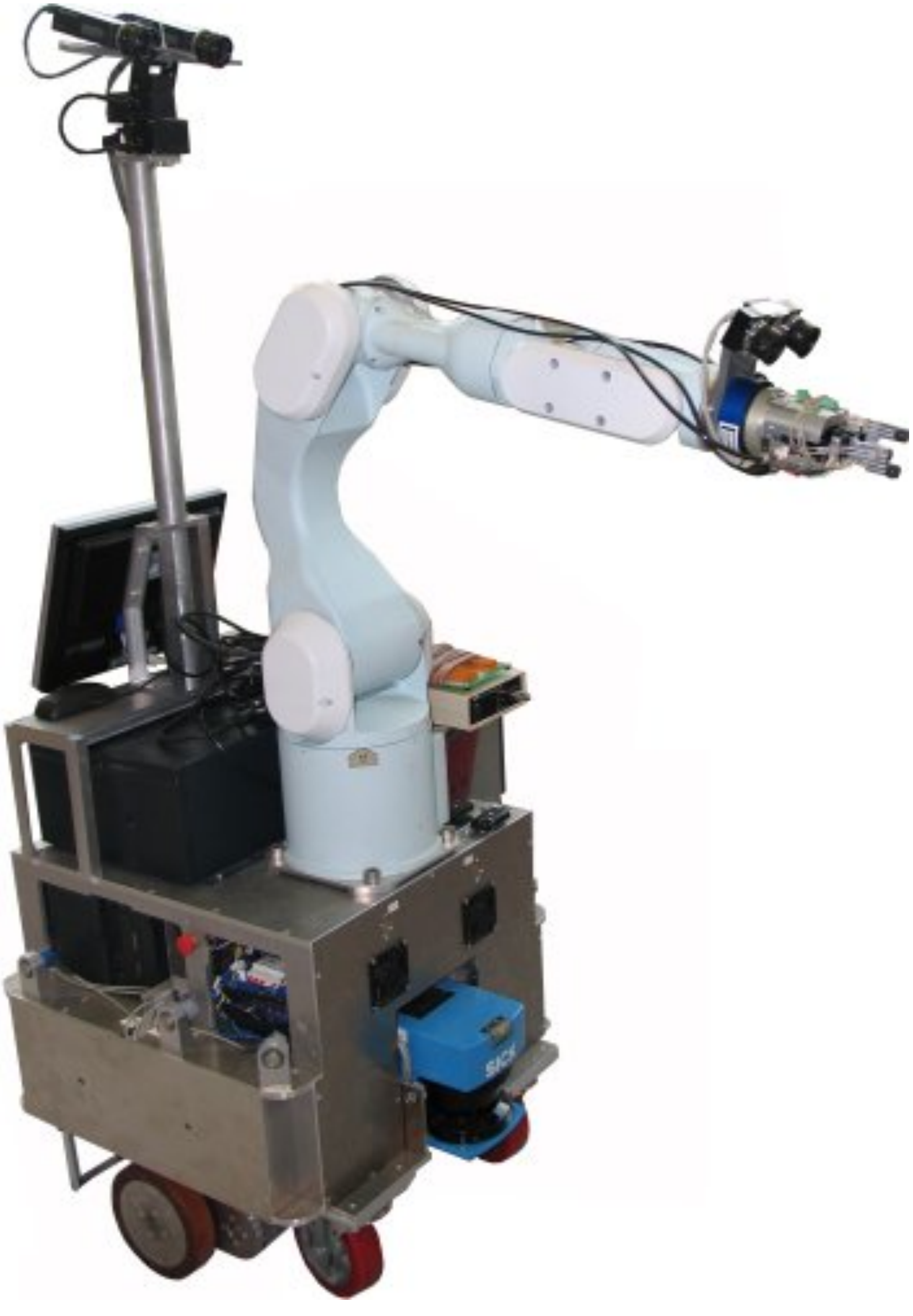
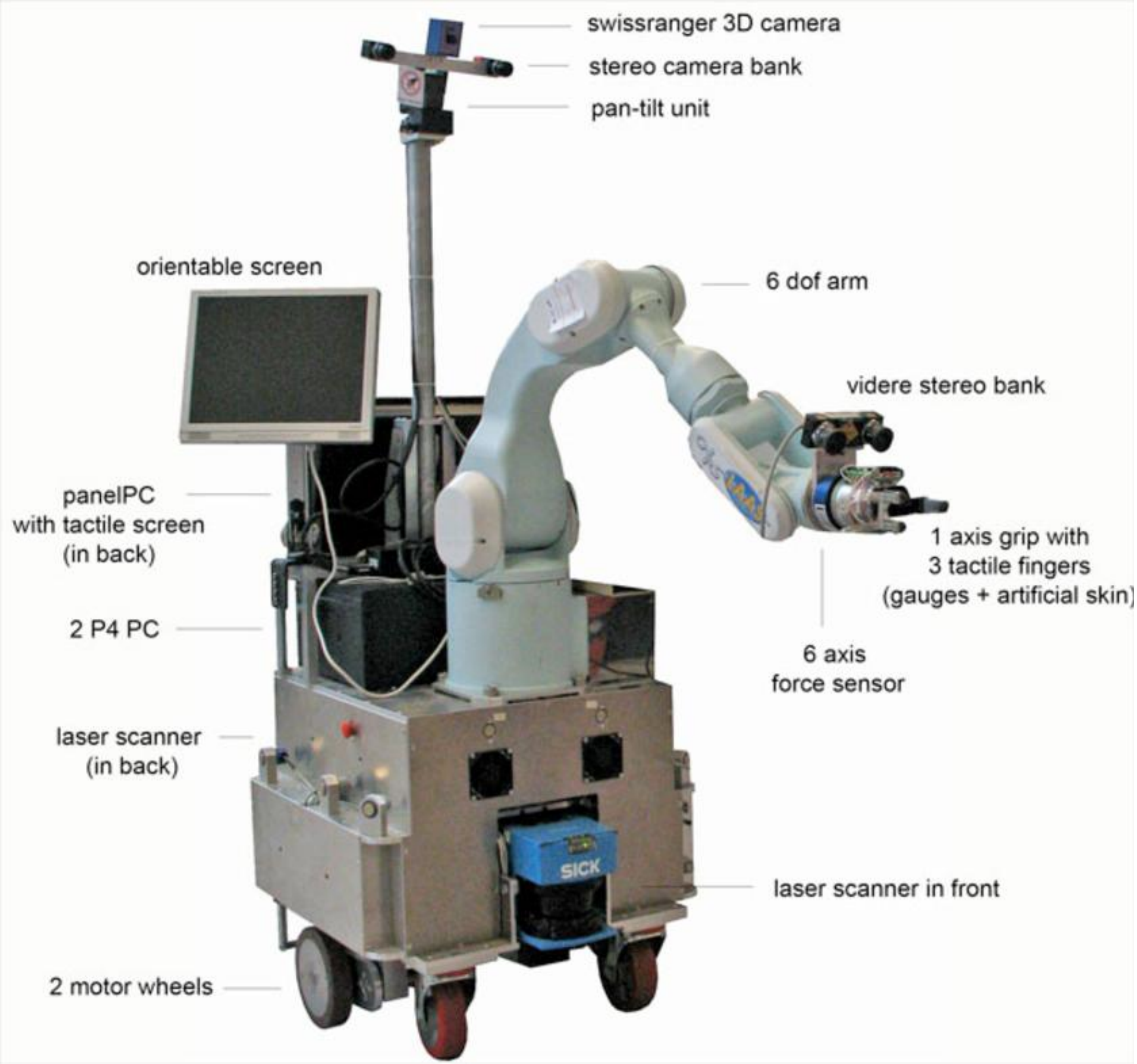
Adapted from a presentation by Dr. Kee Moon

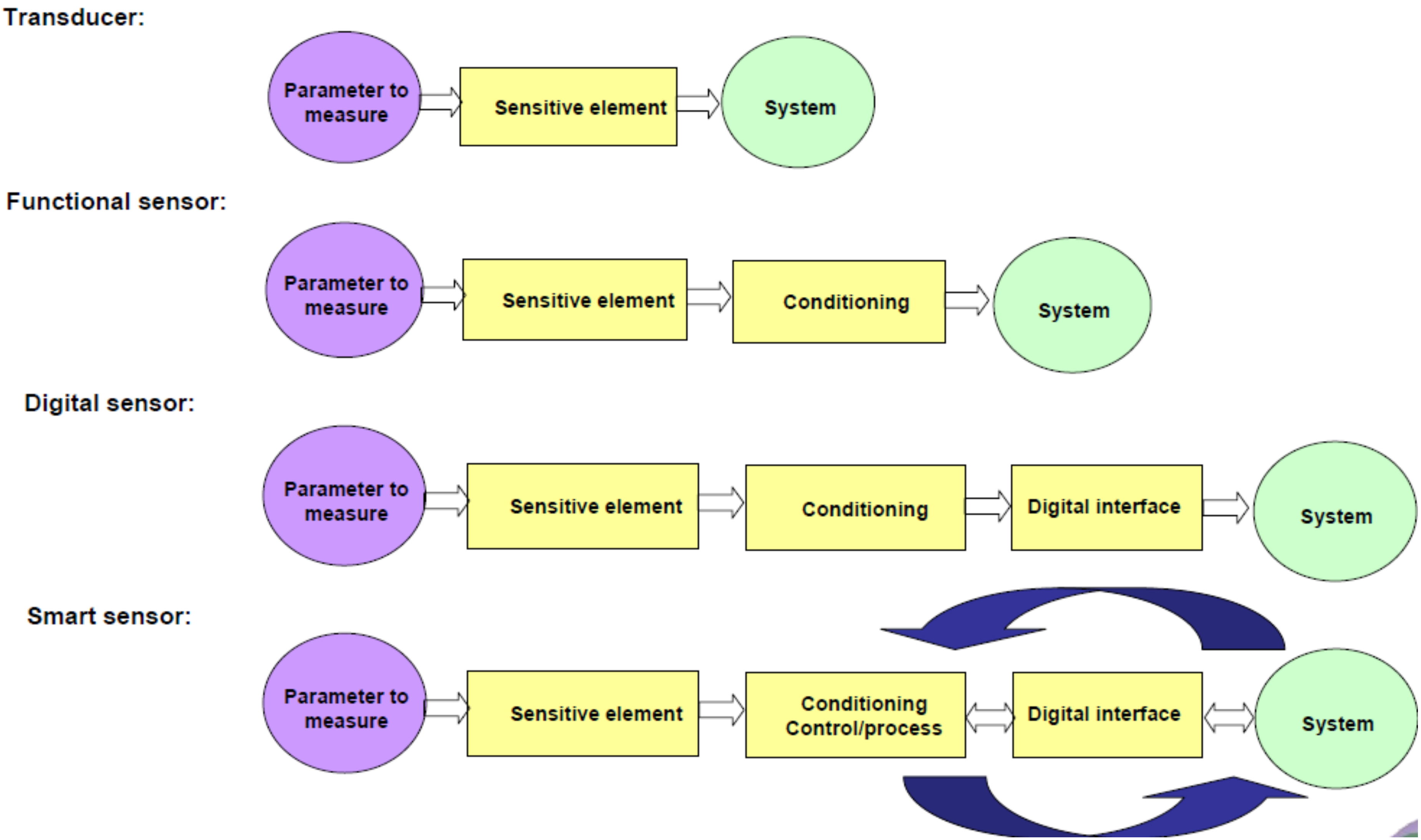
www.youtube.com/watch?v=gK0e9zbYQXY
http://www.laas.fr/robots/jido/data/en/jido.php


SICK


swissranger 3D camera
stereo camera bank
pan-tilt unit
orientable screen
6 dof arm
videre stereo bank
panelPC
with tactile screen
(in back)
1 axis grip with
3 tactile fingers
(gauges + artificial skin)
2 P4 PC
6 axis
force sensor
laser scanner
(in back)
SICK
laser scanner in front
2 motor wheels

Sensors and Transducers

- A ***sensor*** is a device that responds to or detects a physical quantity and transmits the resulting signal to a controller.
- A ***transducer*** is a sensor that converts (transduces) one form of energy to another form.
- Basic types of sensors:
  - ***Absolute*** The output is always relative to a fixed reference, regardless of the initial conditions.
  - ***Analog*** The output is continuous and proportional to the physical quantity being measured.
  - ***Digital*** The output can only change by an incremental value given a change in the measured physical quantity.



Transducer:

Parameter to measure → Sensitive element → System

Functional sensor:

Parameter to measure → Sensitive element → Conditioning → System

Digital sensor:

Parameter to measure → Sensitive element → Conditioning → Digital interface → System

Smart sensor:

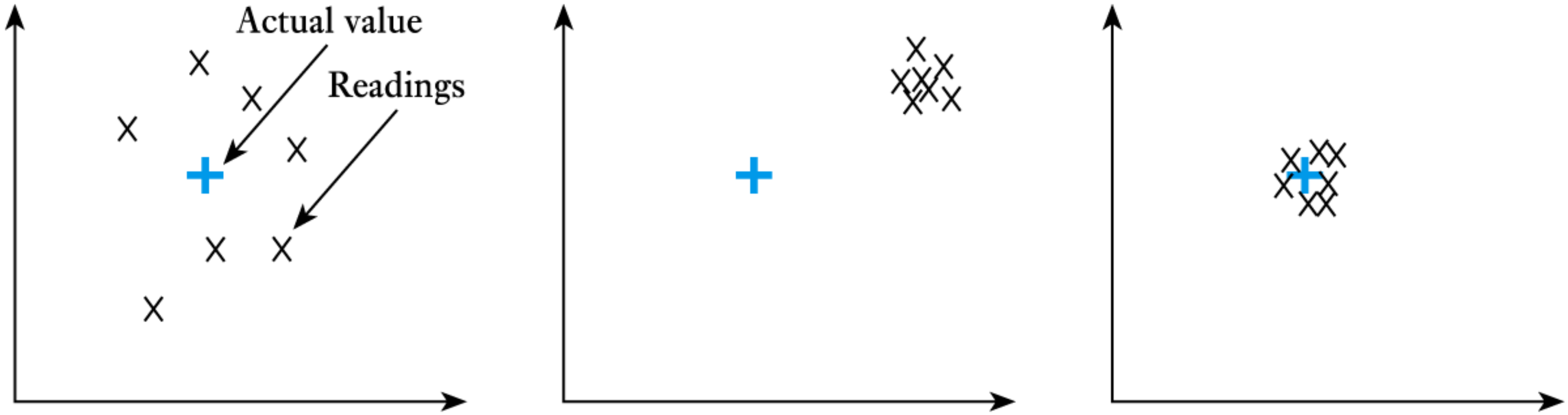
Parameter to measure → Sensitive element → Conditioning Control/process ⇔ Digital interface ⇔ System

Describing Sensor Performance

- Range♪
  - maximum and minimum values that can be measured♪
- Resolution or discrimination♪
  - smallest discernible change in the measured value♪
- Error♪
  - difference between the measured and actual values♪
    - random errors♪
    - systematic errors♪
- Accuracy, inaccuracy, uncertainty♪
  - accuracy is a measure of the maximum expected error♪

Precision and accuracy♪

a measure of the lack of random errors (scatter)♪



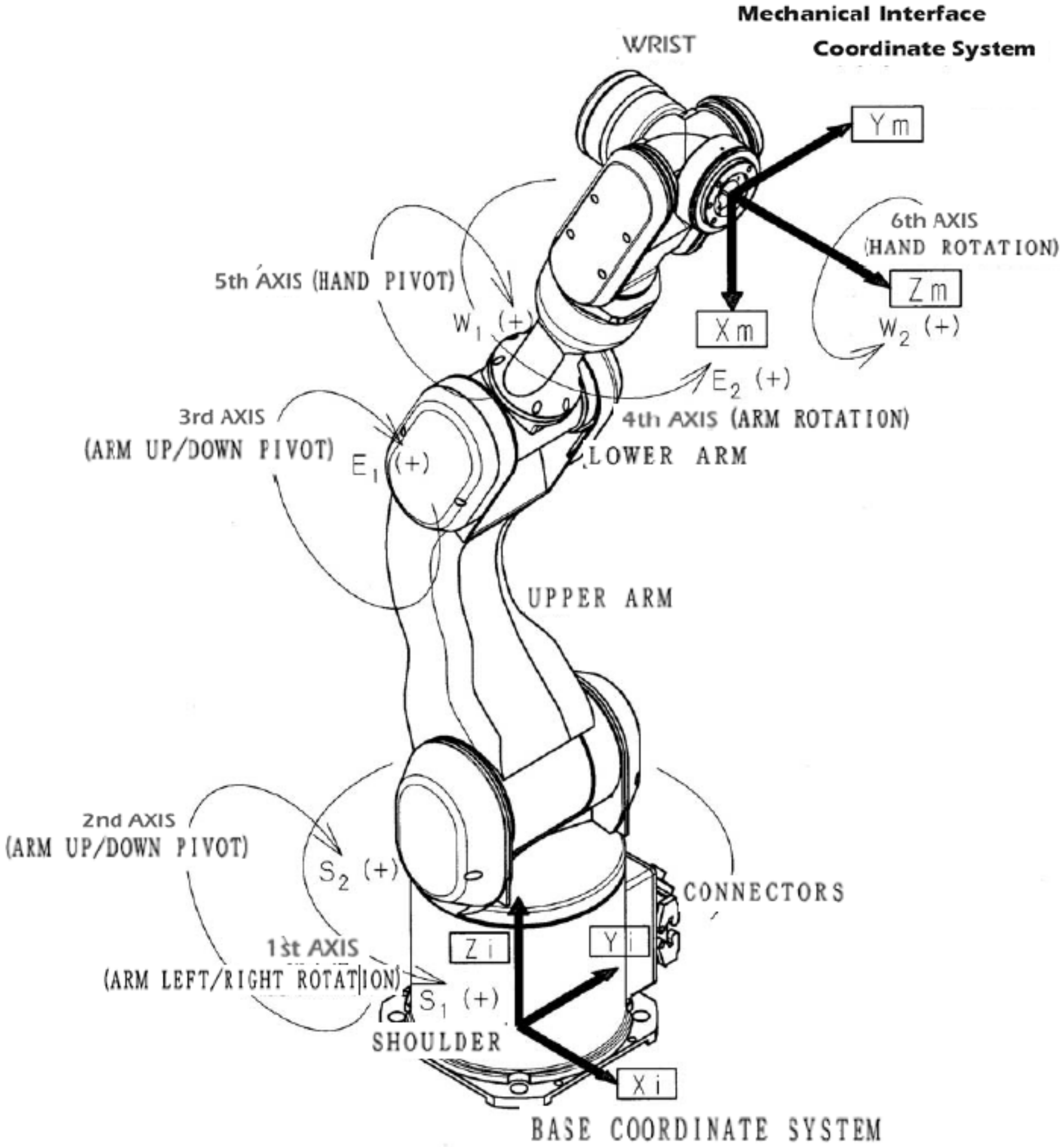
(a) Low precision, low accuracy

(b) High precision, low accuracy

(c) High precision, high accuracy

Precision and accuracy♪

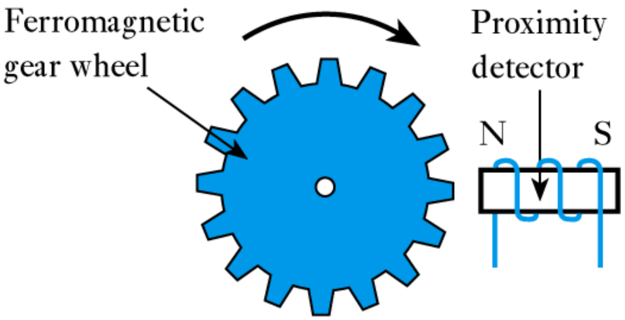
- Linearity♪
  - maximum deviation from a ‘straight-line’ response♪
  - normally expressed as a percentage of the full-scale value♪
- Sensitivity♪
  - a measure of the change produced at the output for a given change in the quantity being measured♪


Mechanical Interface
Coordinate System
WRIST
Ym
6th AXIS
(HAND ROTATION)
Zm
5th AXIS (HAND PIVOT)
W1 (+)
Xm
W2 (+)
E2 (+)
3rd AXIS
(ARM UP/DOWN PIVOT)
E1 (+)
4th AXIS (ARM ROTATION)
LOWER ARM
UPPER ARM
2nd AXIS
(ARM UP/DOWN PIVOT)
S2 (+)
CONNECTORS
Zi
Yi
1st AXIS
(ARM LEFT/RIGHT ROTATION)
S1 (+)
SHOULDER
Xi
BASE COORDINATE SYSTEM

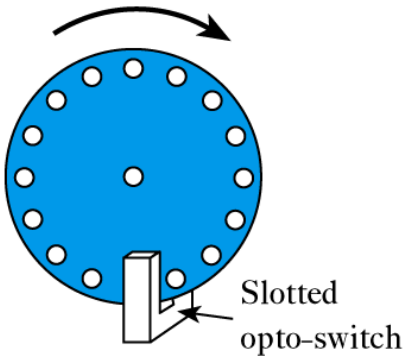
Position sensors♪

several methods use counting to determine position♪

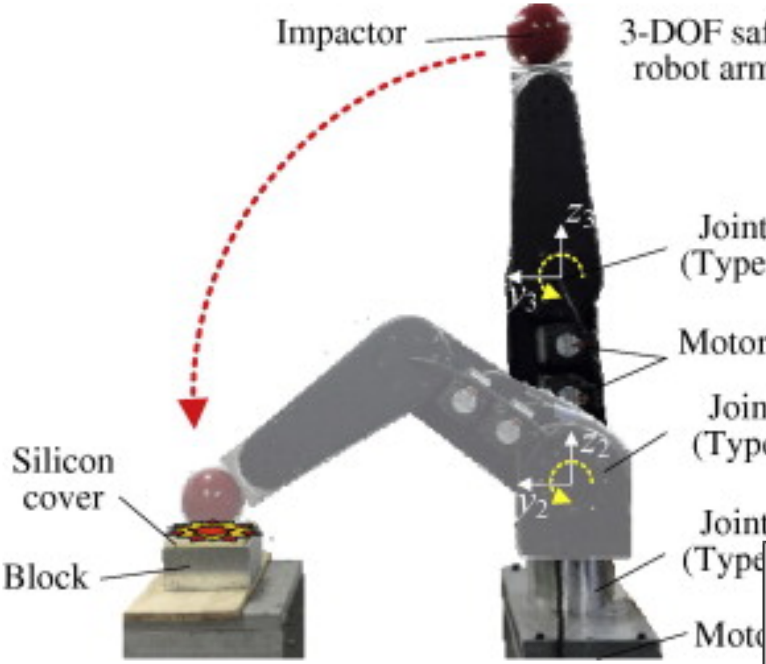
- two examples are given below♪

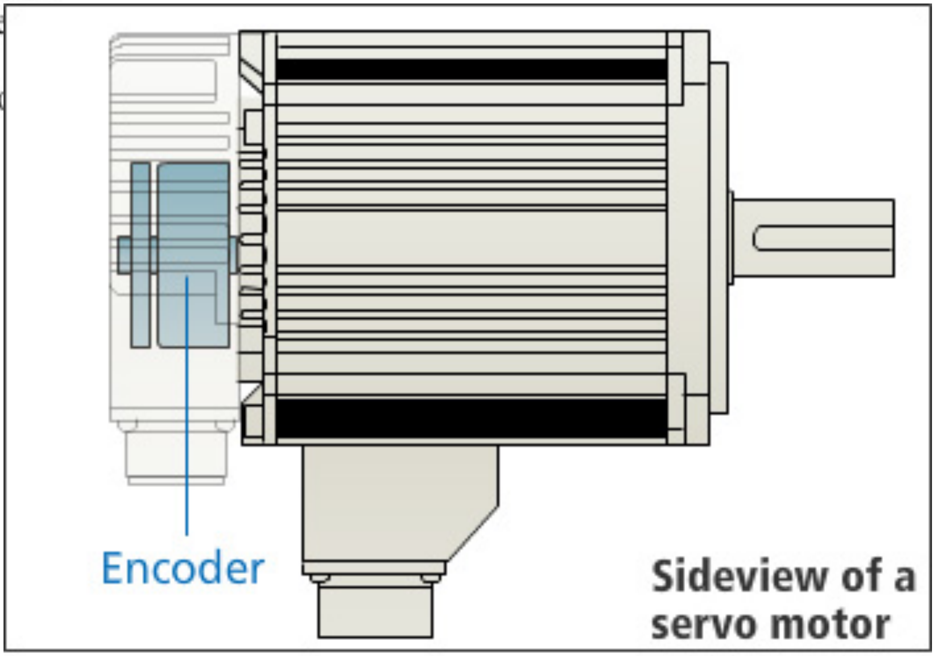


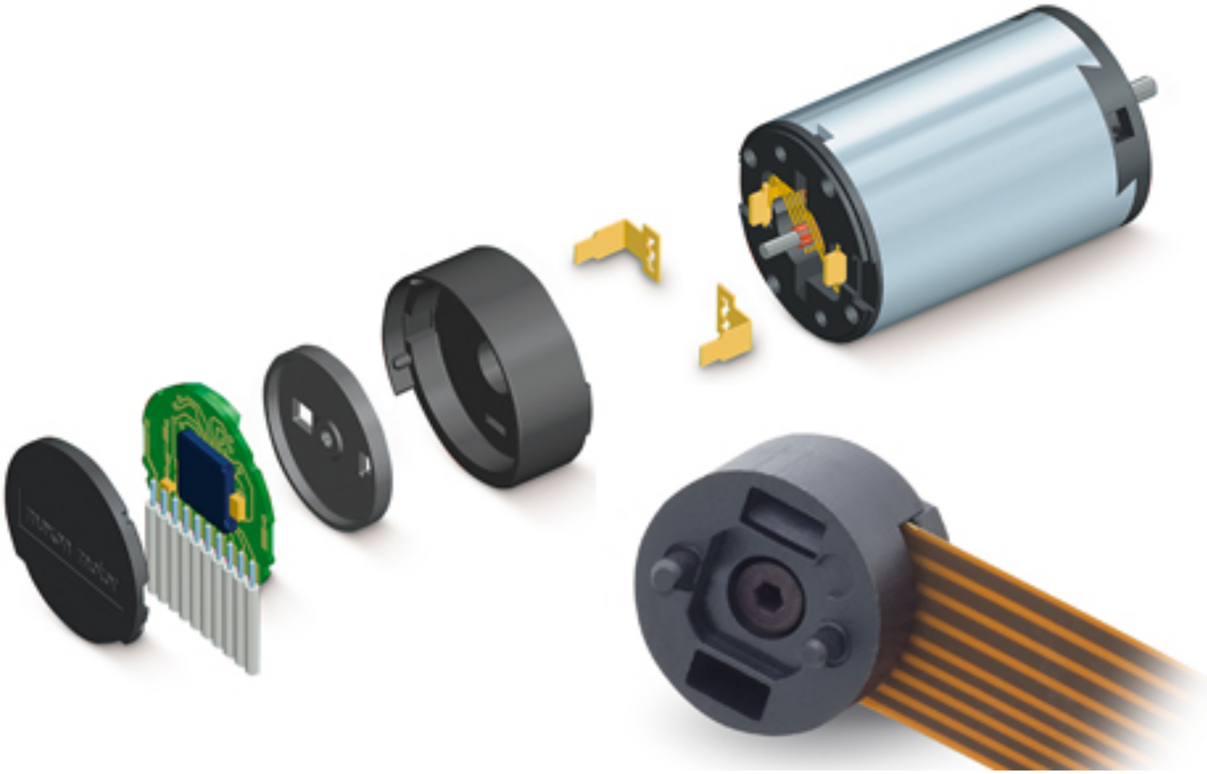
Inductive sensor



Opto-switch sensor

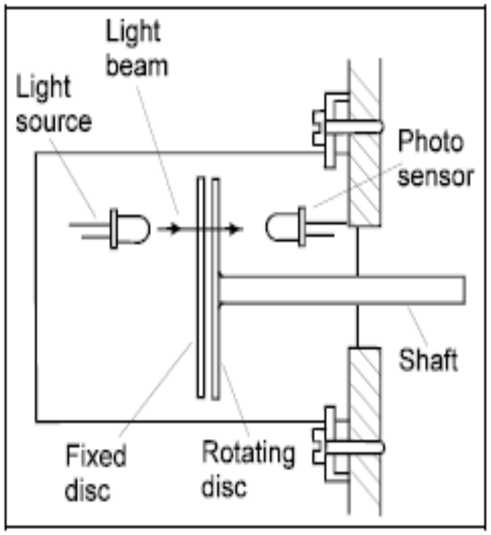

Impactor
3-DOF safe robot arm
z_3
y_3
Joint 3 (Type A)
Motor
Joint 2 (Type B)
z_2
y_2
Silicon cover
Block
Joint 1
(Type
Moto

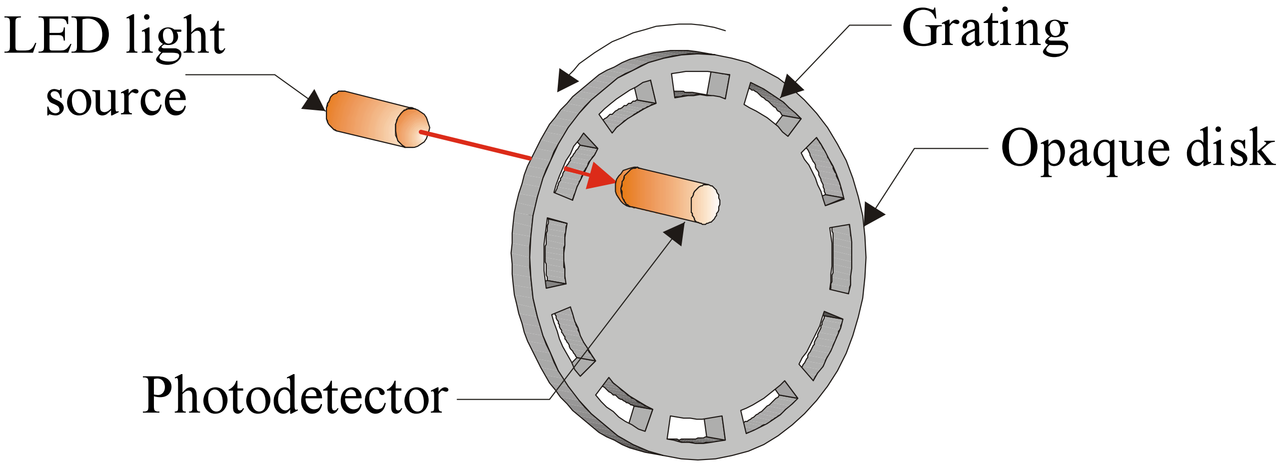

Encoder
Sideview of a servo motor



Incremental Encoders

- Digital transducers output data as discrete pulses or coded (digital) information.
- Optical rotary encoders can use *geometric masking*, which allows light to pass through unmasked slits (grating) and be detected by photodetectors on the other side of the disk:

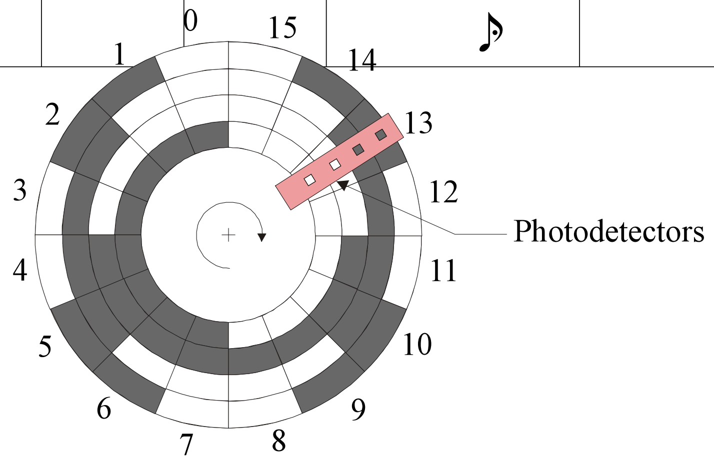




Absolute Encoders

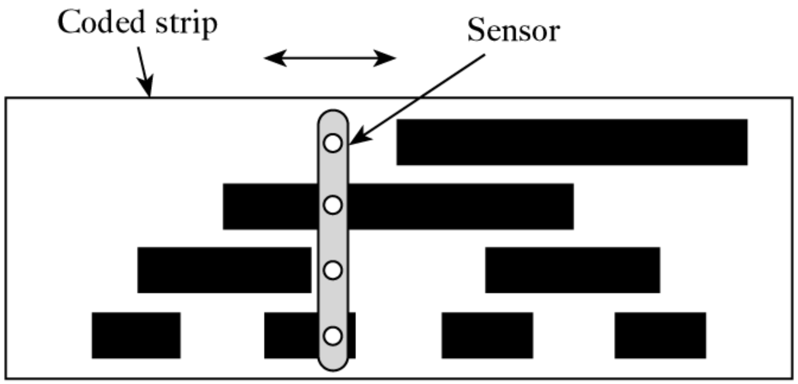
- An absolute encoder, yielding 16 distinct outputs, employing the Gray-coding scheme - The Gray code allows transition of only one bit of data between two consecutive sector numbers:♪

0	1	2	3	4	. . . . ♪	13	14	15
0111	0110	0100	0101	0001	. . . . ♪	1100	1110	1111



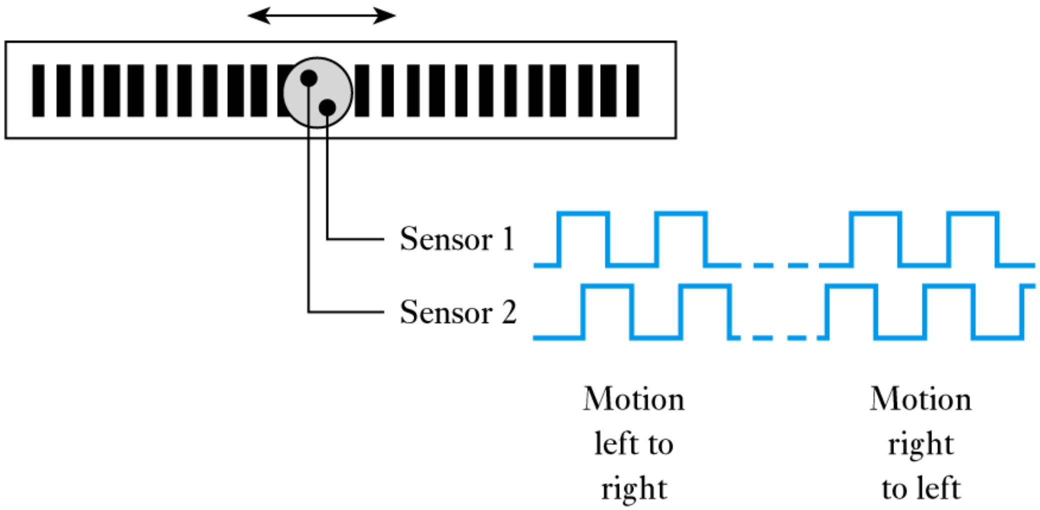
Position encoders♪

- Absolute position encoders♪
  - a pattern of light and dark strips is printed on to a strip and is detected by a sensor that moves along it♪
    - the pattern takes the form of a series of lines as shown below♪
    - it is arranged so that the combination is unique at each point♪
    - sensor is an array of photodiodes♪



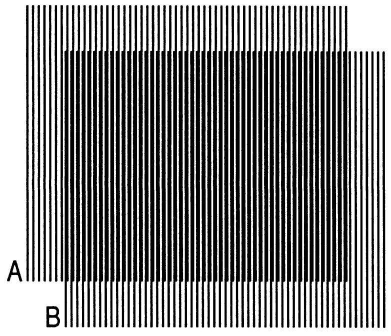
Position encoders♪

- Incremental position encoder♪
  - uses a single line that alternates black/white♪
    - two slightly offset sensors produce outputs as shown below♪
    - detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset)♪

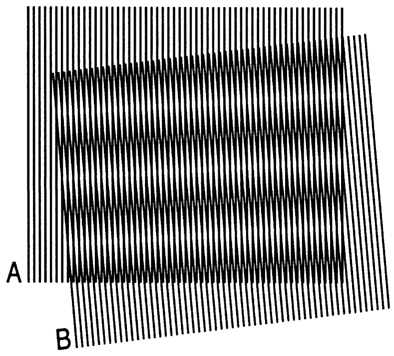


Interferometric encoders

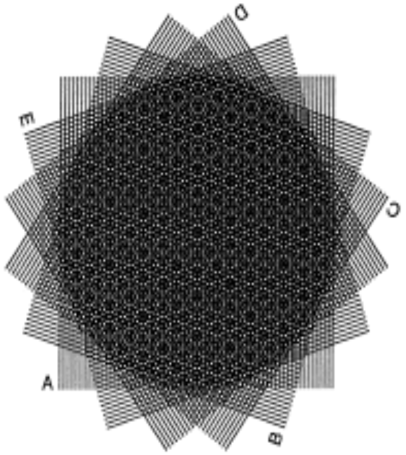
- the moir´e effects:
  - The superposition of periodic structures (such as linegratings, dot-screens, etc.) offers a wide range of interesting properties for exploration

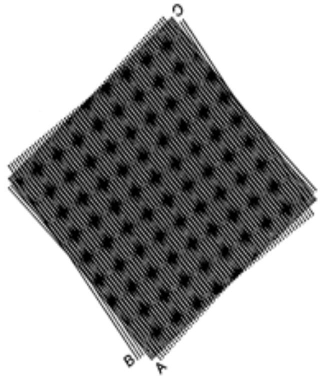


(a)

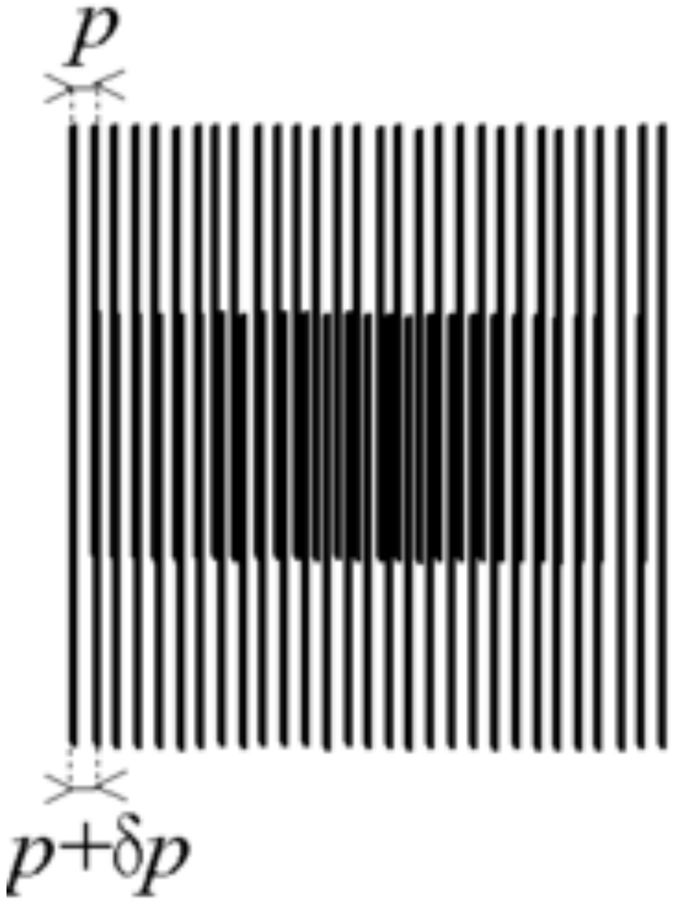


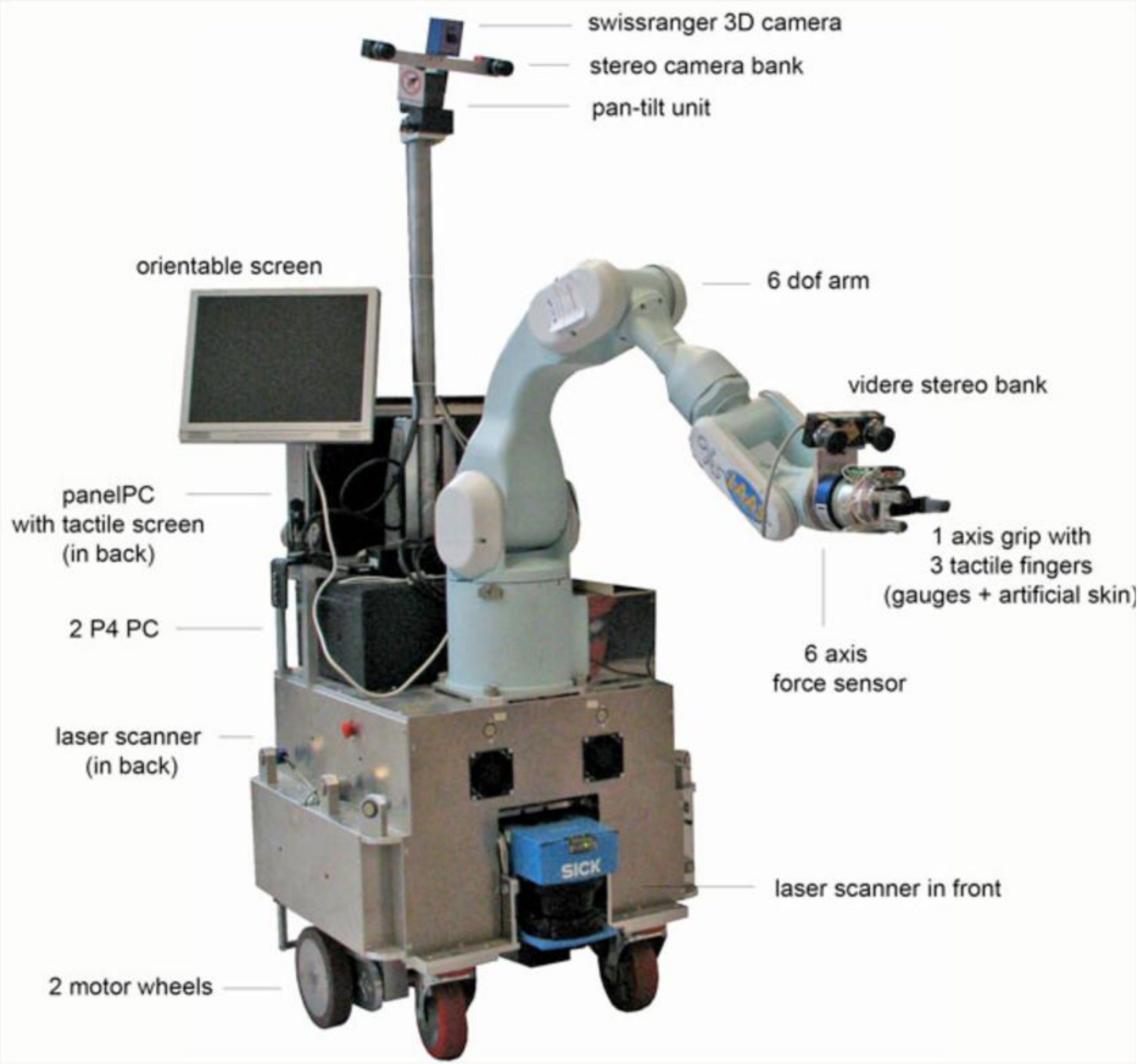
(b)





Superimpose of two patterns




swissranger 3D camera
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with tactile screen
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2 motor wheels
SICK

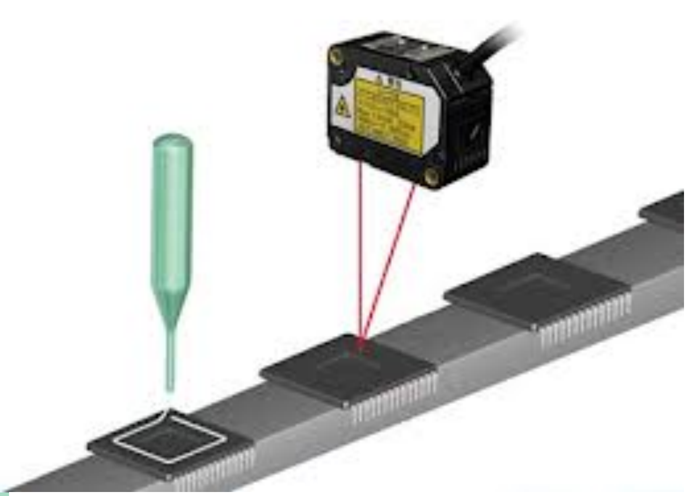
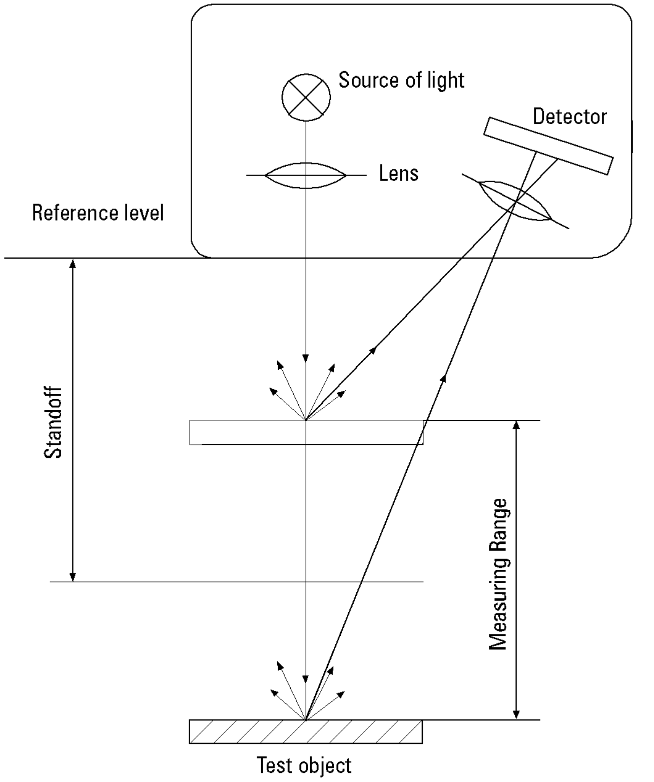
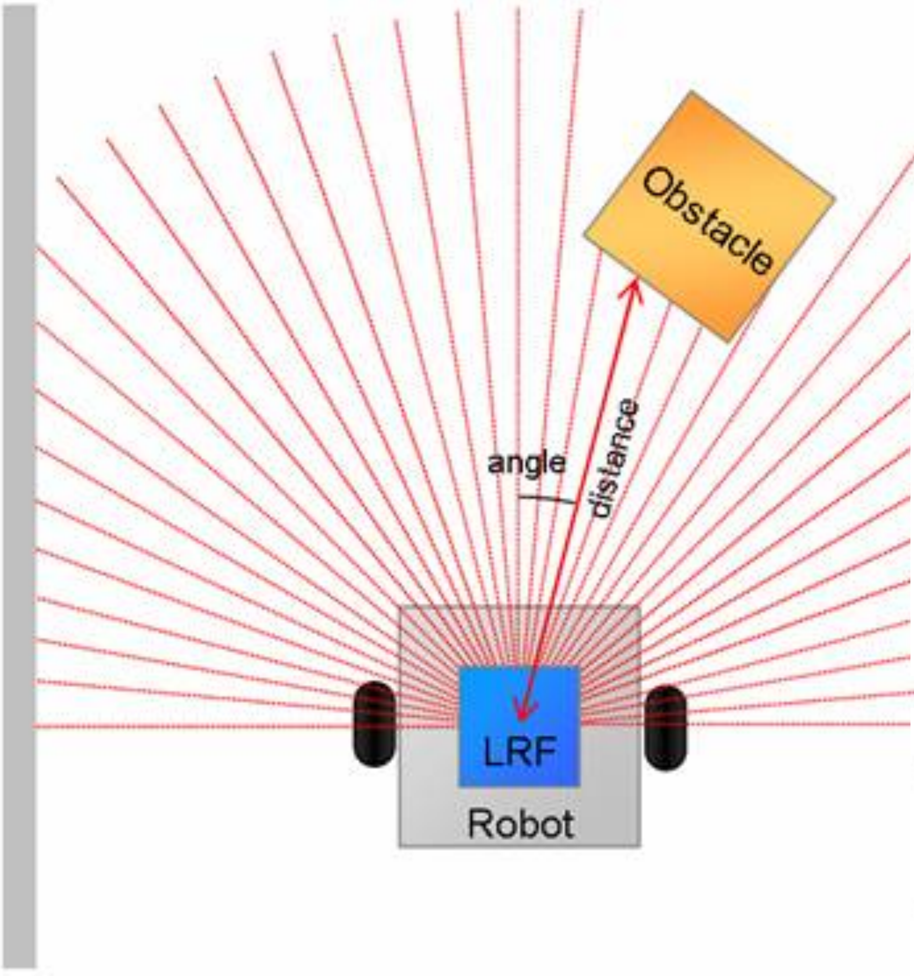
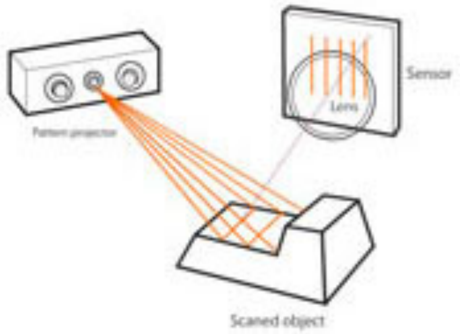
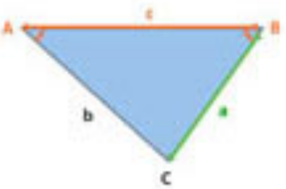


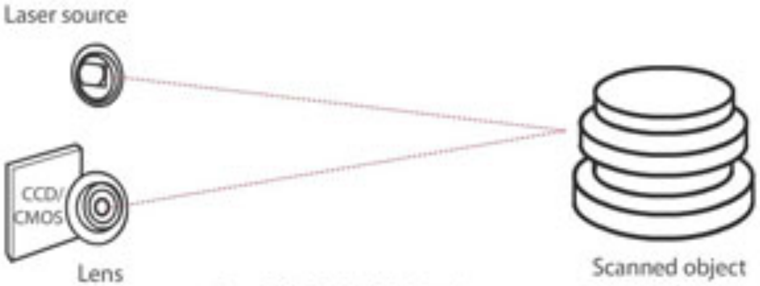
Figure 1 Measurement by a laser triangulations sensor



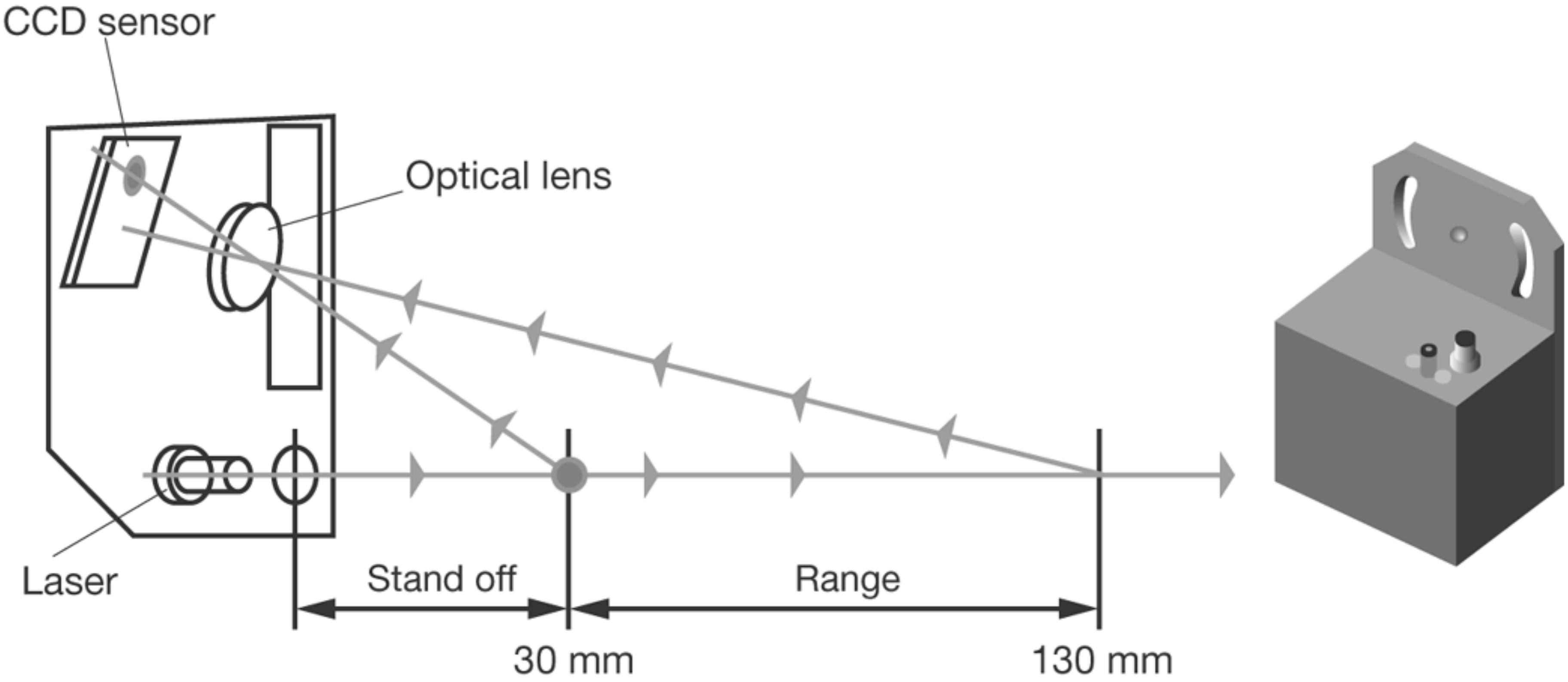








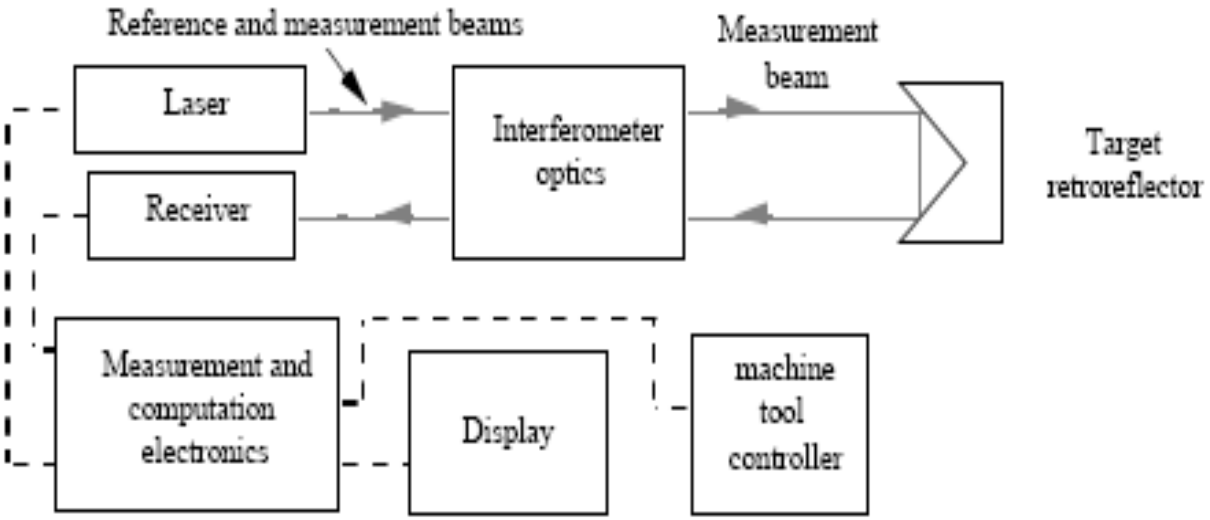
C = 299,792,458 m/sec
= 3.3 nanoseconds/m

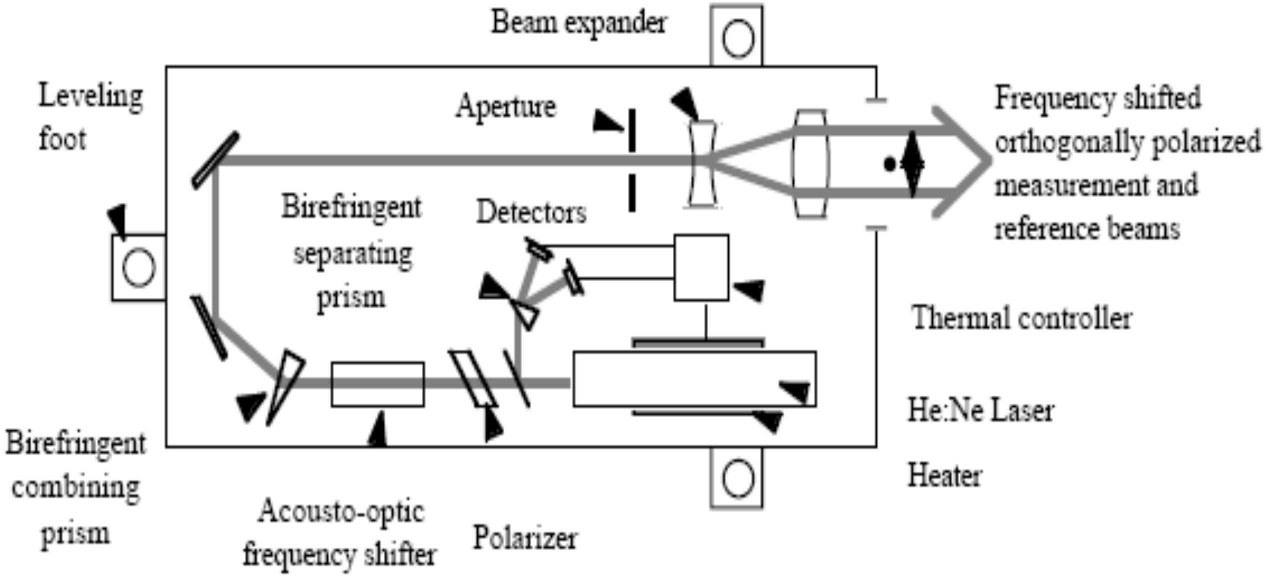

CCD sensor
Optical lens
Laser
Stand off
Range
30 mm
130 mm

Optical Heterodyne Interferometers

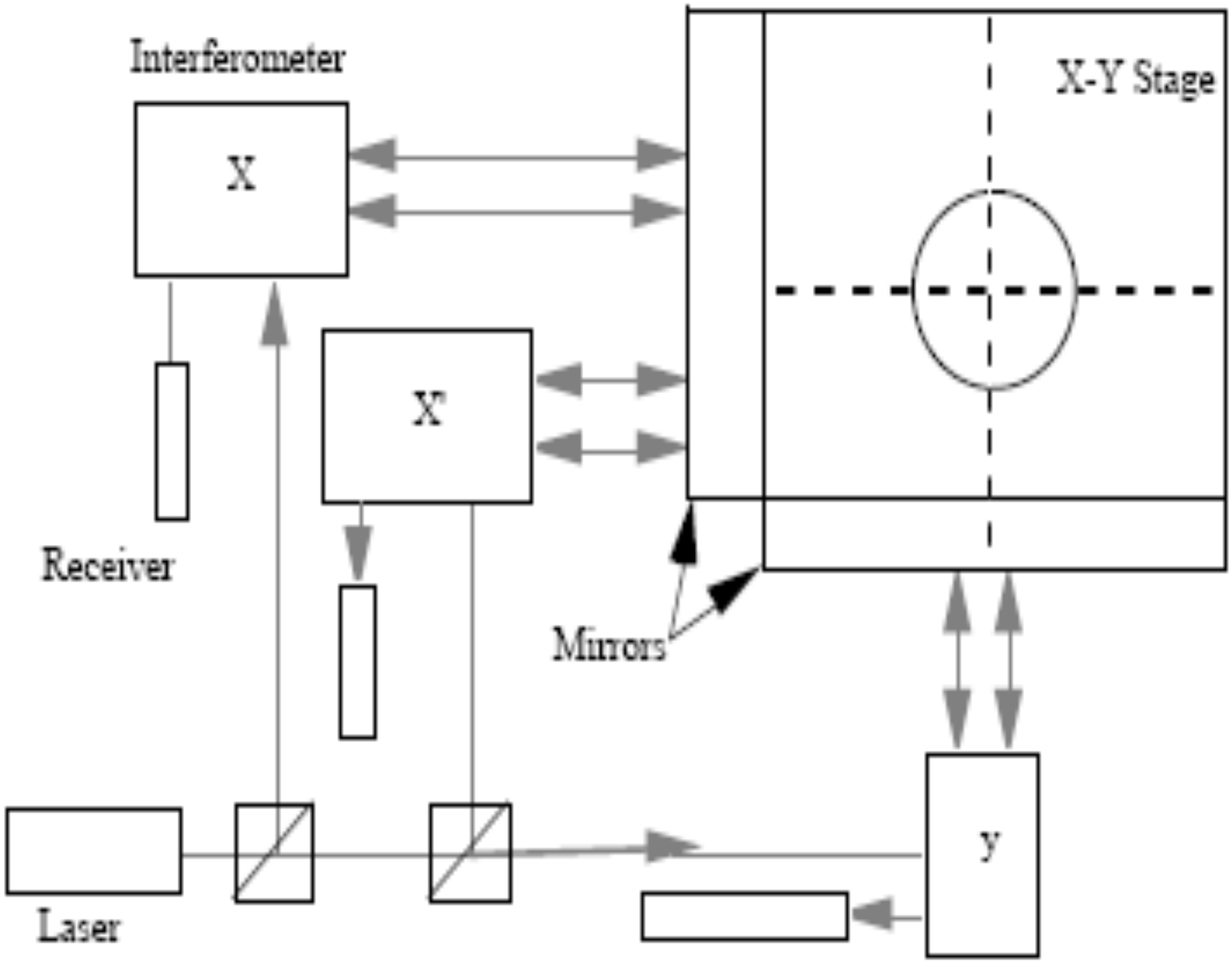
- **Michelson interferometers** count fringes which limits the resolution to about l/8.
- **Heterodyne** techniques can be used to achieve two orders of magnitude greater resolution:

Construction of a laser head used with an Optical Heterodyne Interferometer

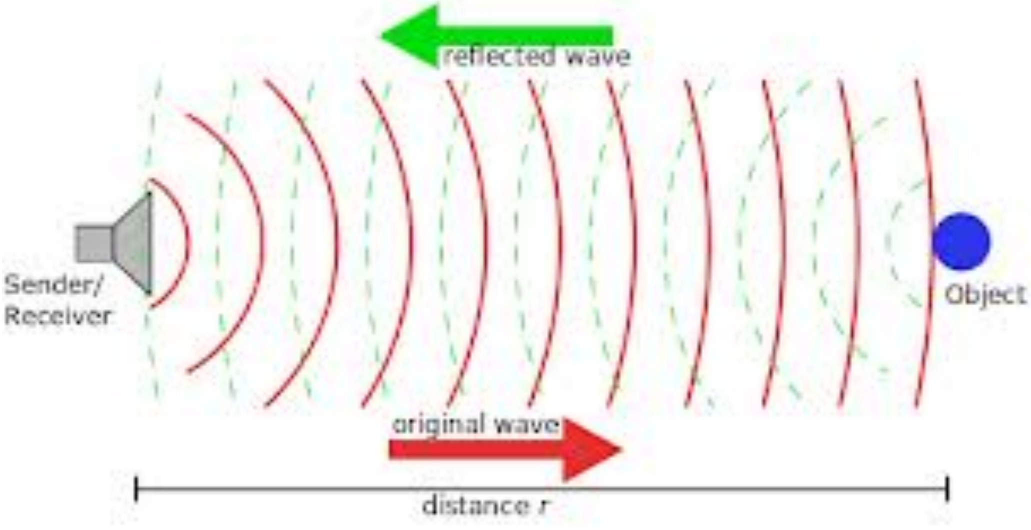


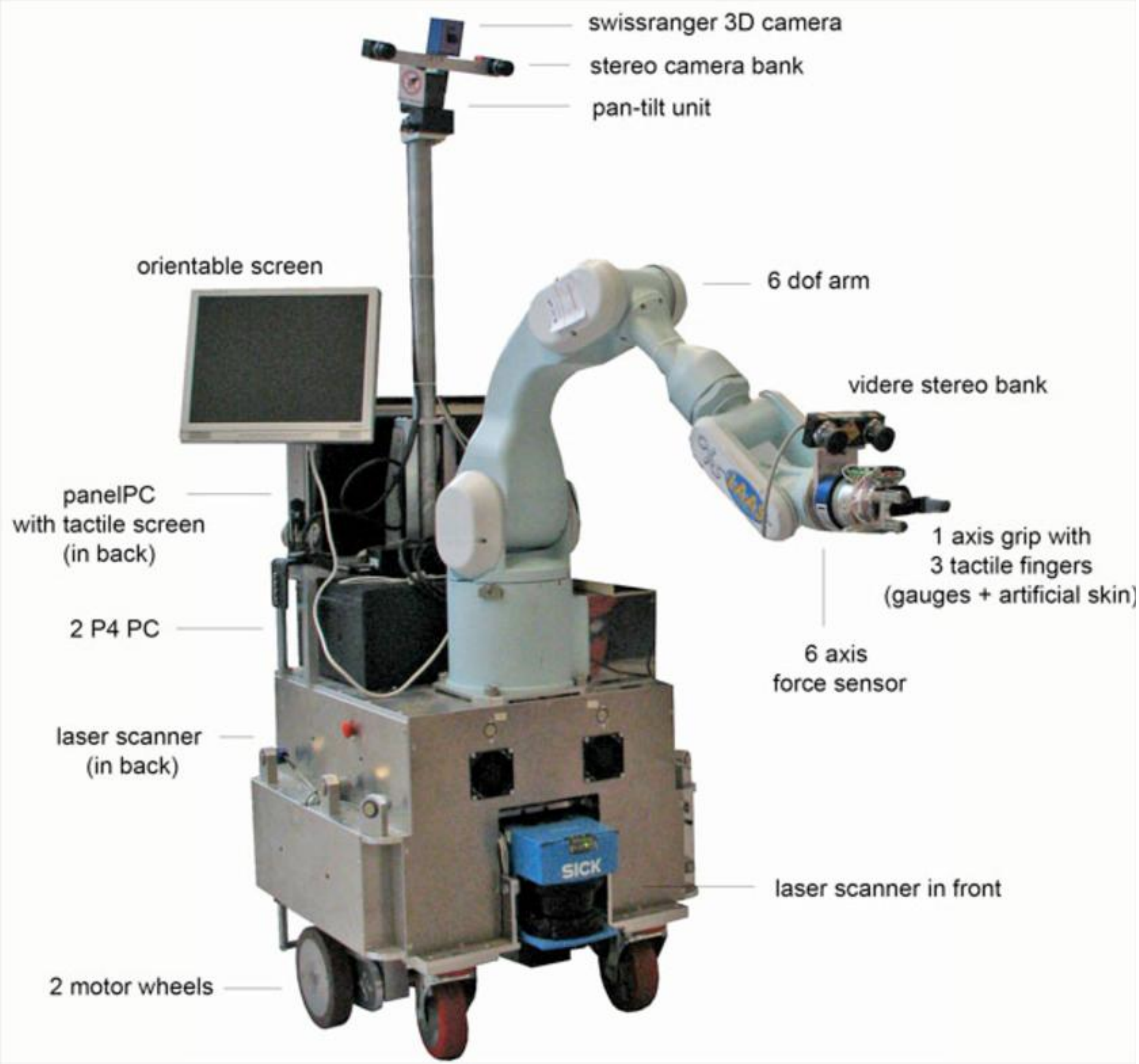


Typical wafer stage metrology using a laser measurement system



Ultrasound range sensor




swissranger 3D camera
stereo camera bank
pan-tilt unit
orientable screen
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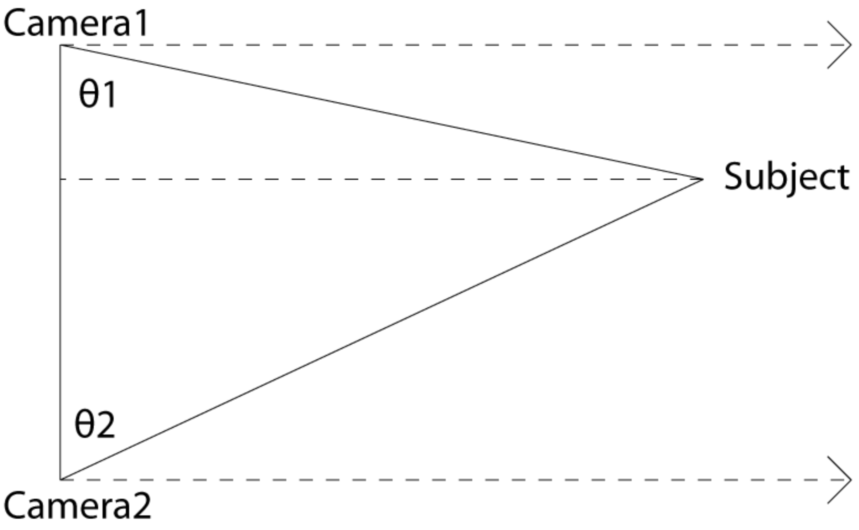
videre stereo bank
panelPC with tactile screen (in back)
1 axis grip with 3 tactile fingers (gauges + artificial skin)
2 P4 PC
6 axis force sensor
laser scanner (in back)
laser scanner in front
2 motor wheels

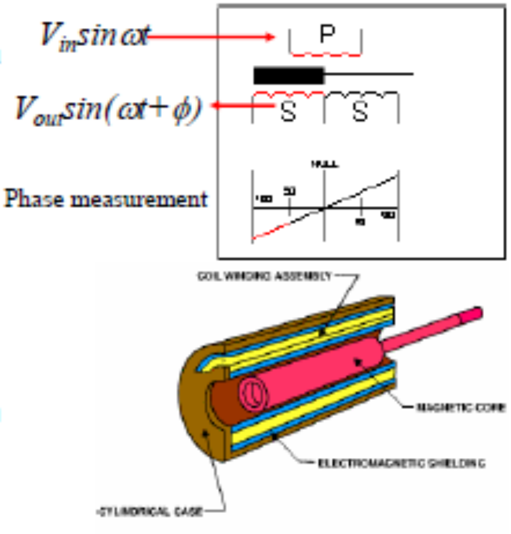
Stereo camera sensor



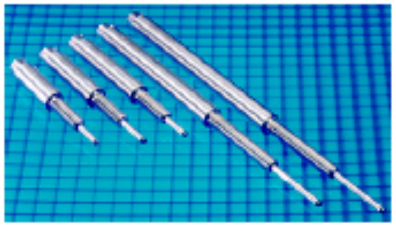
LVDT

Linear Variable Differential Transformer (LVDT)

- An LVDT consists of a magnetic core that moves in a cylinder
- The sleeve of the cylinder contains a primary coil that is driven by an oscillating voltage
- The sleeve also contains two secondary coils that detect this oscillating voltage with a magnitude equal to displacement
- The automatic nulling that can be achieved using two coils makes LVDTs very accurate (submillimetre)

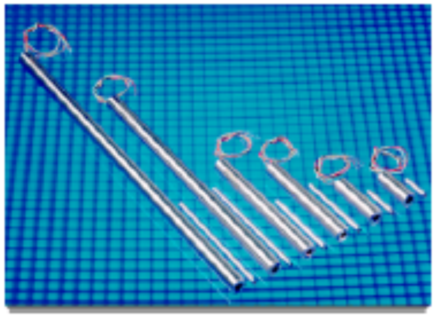


Example LVDTs

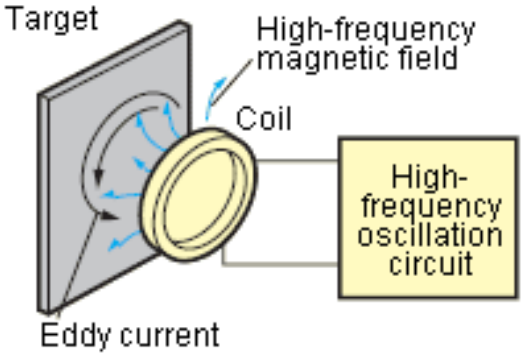


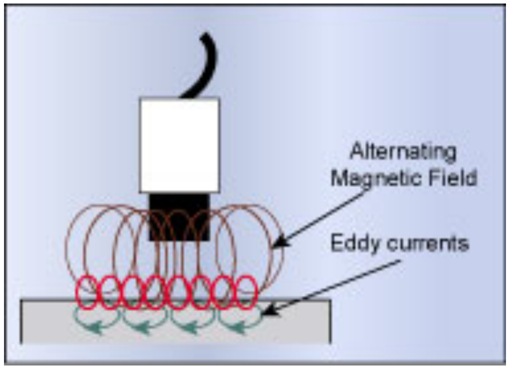
Spring-loaded
Standard for use
In hydraulic cylinders

Free core LVDTs for
use in hostile environments
And total emersion



Eddy current displacement sensor



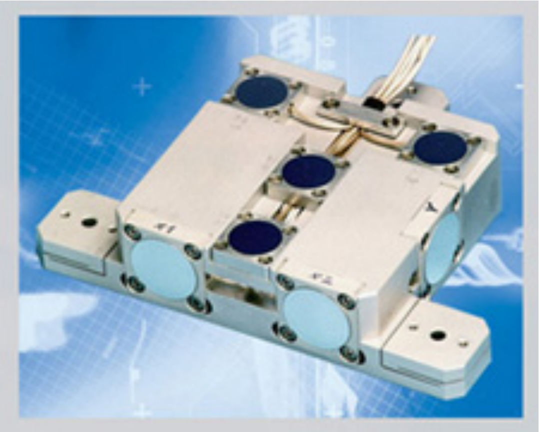


The Capacitive Sensor

- Capacitive gages (capacitance sensors) are the nanometrology system of choice for the most demanding precision positioning, scanning and measurement applications.
- Two plate capacitive displacement sensors ensure highest linearity and longterm stability. These non-contact devices detect motion at sub-nanometer levels directly (direct metrology).
- They provide accuracy, linearity, resolution, stability and bandwidth superior to conventional sensors such as LVDTs, strain gauge type sensors (piezo resistive sensors), and incremental encoders (glass scale type encoders).

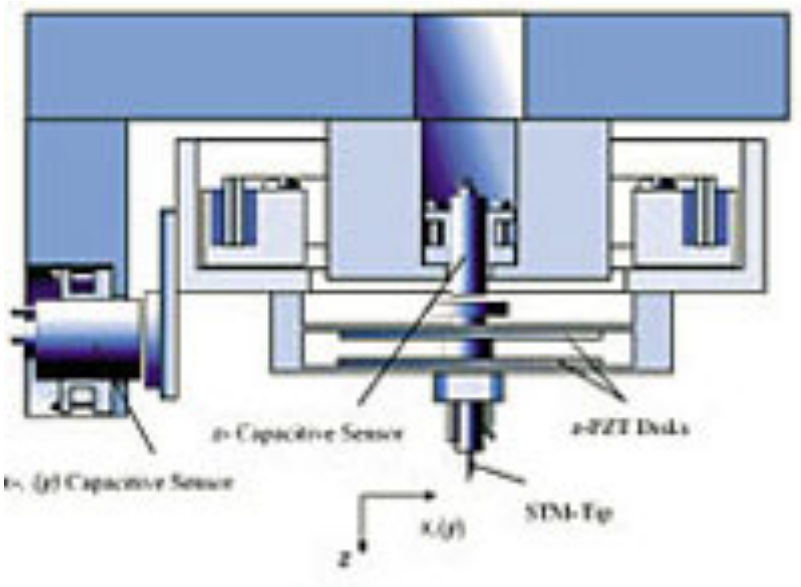
Applications

- Capacitive sensors are especially well-suited for parallel metrology configurations. In multi-axis nanopositioning systems, parallel metrology means that the controller monitors all controlled degrees of freedom relative to "ground" (the fixed frame) and uses each actuator to compensate the undesired off-axis motion of the others automatically As a result, it is possible to keep deviations in the sub-nanometer and sub-microradian range.
- Resolution on the order of picometers is achievable with short-range, two-electrode capacitive position sensors.
- Theoretical measurement resolution is limited only by quantum noise. In practical applications, stray radiation, electronics-induced noise and geometric effects are the limiting factors. For example, with the 100 µm range

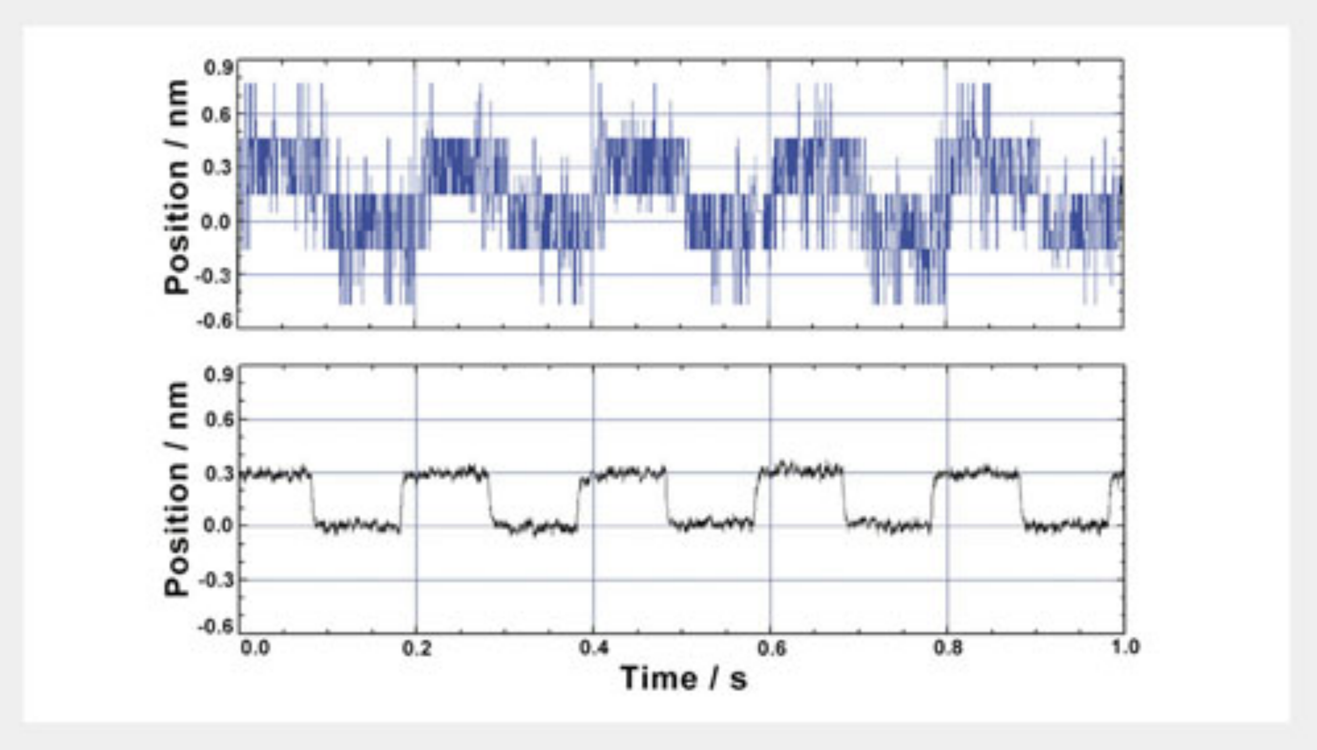


Capacitive position sensors in an ultra-high-accuracy,
six-axis nanopositioning system designed by
PI for the German Institute of Standards (PTB). Application: scanning microscopy

Applications



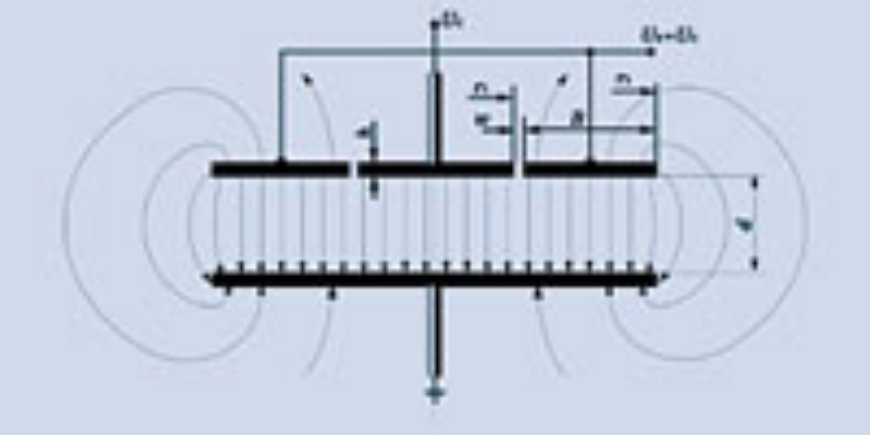
(scanning tunneling microscope) with integrated capacitive position sensors



Piezo nanopositioning system making 0.3 nm steps, measured with PI capacitive sensor (lower curve) and with a highly precise laser interferometer. The capacitive sensor provides significantly higher resolution than the interferometer

Sensor working principle

- The Farad:
  - Capacitance is measured in Farads, named after Michael Faraday who did pioneering experiments in electricity and magnetism in the middle 1800s. A Farad is a rather large unit. Most capacitors in electronic circuitry are measured in microfarads (µF, 10-6). The capacitance changes sensed by a capacitance gage are around 1 femtofarad (fF, 10-15).
- Capacitive dimensional measurement requires three basic components:
  - a probe that uses changes in capacitance to sense changes in distance to the target,
  - driver electronics to convert these changes in capacitance into voltage changes,
  - a device to indicate and/or record the resulting voltage change.



Two-plate capacitive sensor working principle.

How Capacitance Relates to Distance

$$C = \frac{\text{Area} \times \text{Dielectric}}{\text{Gap}}$$

Capacitance is determined by Area, Gap, and Dielectric (the material in the gap).
Capacitance increases when Area or Dielectric increase, and capacitance decreases when the Gap increases.

$$C \approx \frac{1}{\text{Gap}}$$

Area and Dielectric are held constant for ordinary capacitive sensing so only the Gap can change the capacitance

- The capacitance between two plates is determined by three things:
- Size of the plates: capacitance increases as the plate size increases
- Gap Size: capacitance decreases as the gap increases
- Material between the plates (the dielectric):

Simple parallel structure

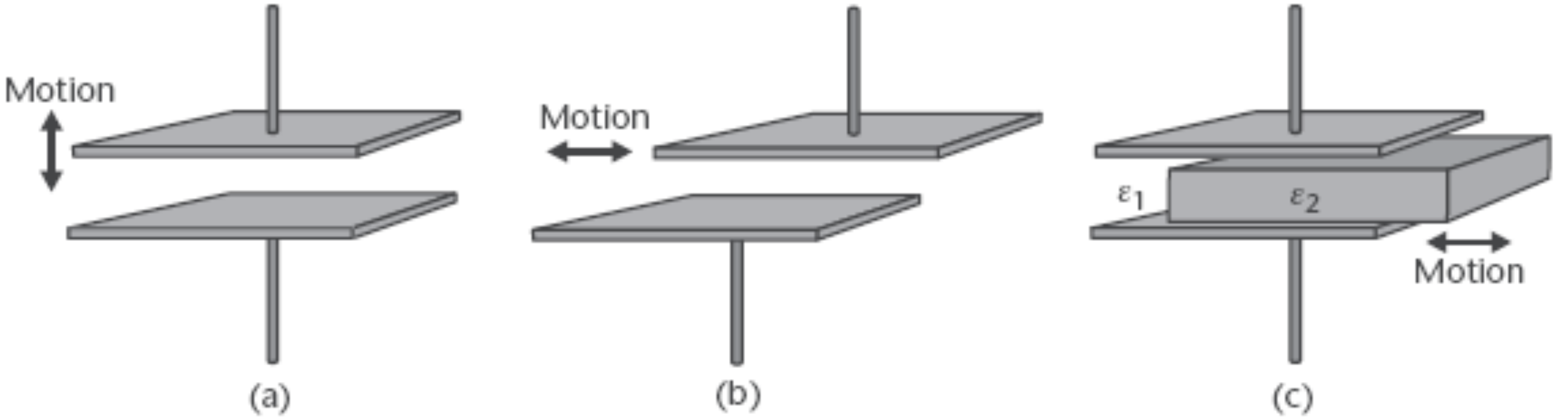


Figure 5.5 Examples of simple capacitance displacement sensors: (a) moving plate, (b) variable area, and (c) moving dielectric.

Differential capacitance sensor

$$(V_2 - V_1) = V_s\left(\frac{x}{d}\right) \qquad (5.18)$$

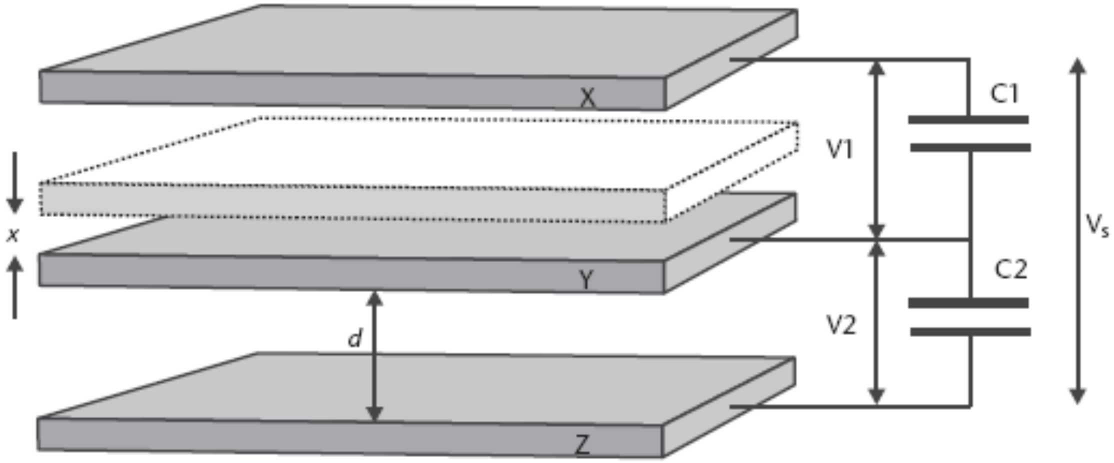
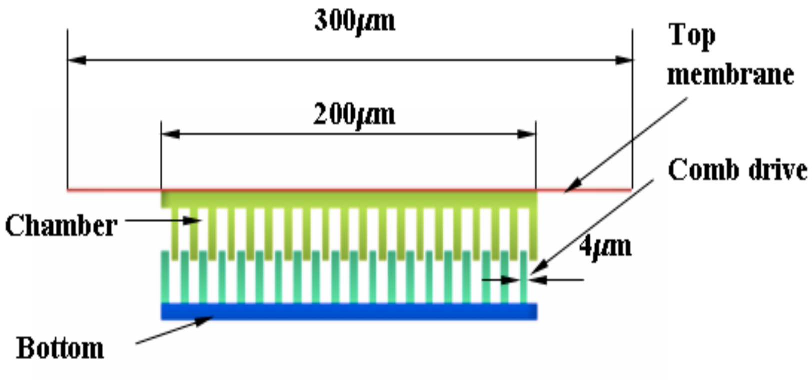
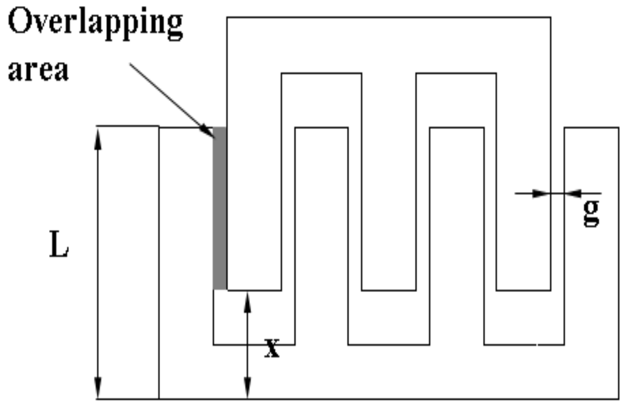


Figure 5.6 A differential capacitance sensor.

Comb-drive capacitance sensor

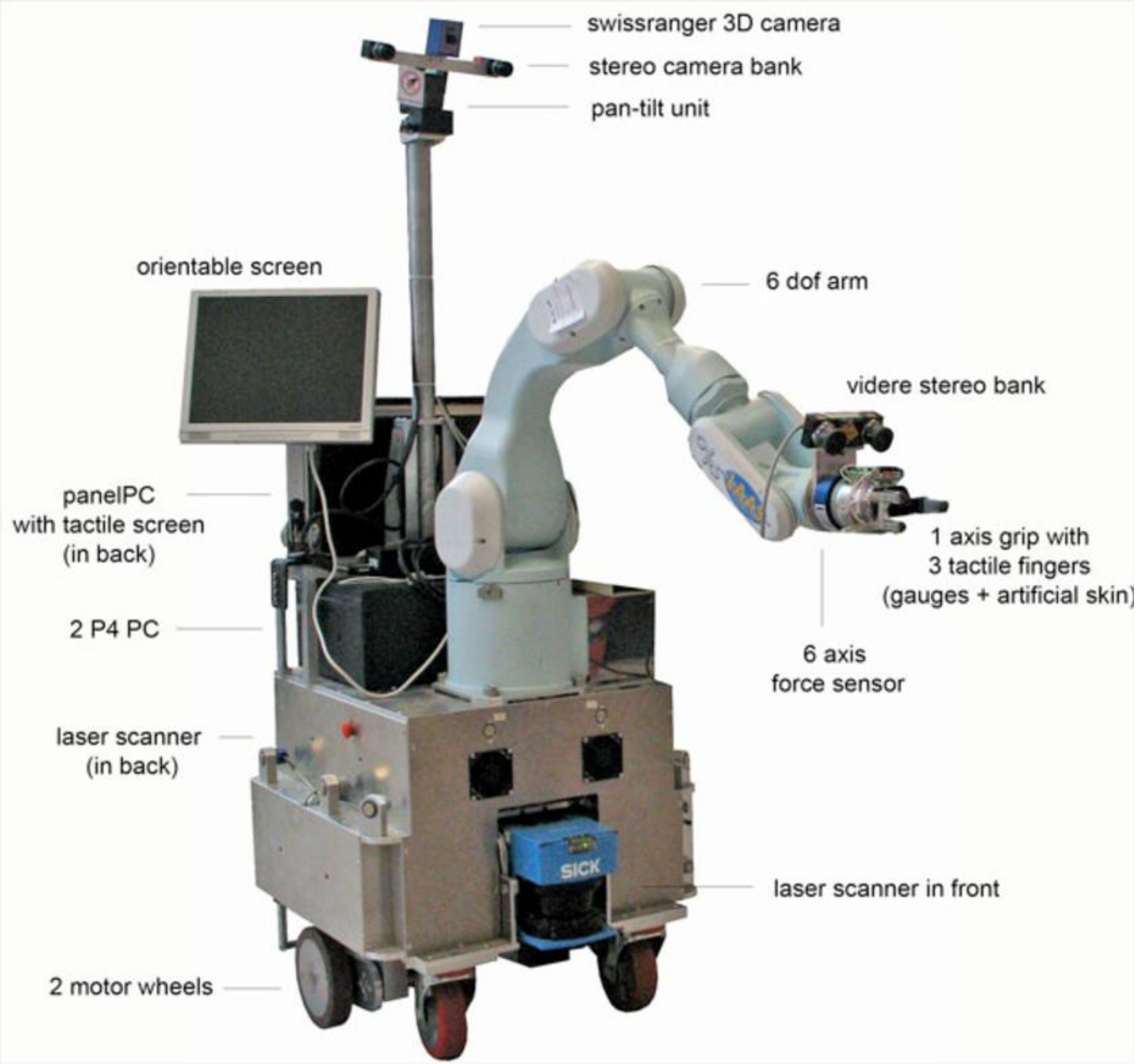




The comb-drive has an inter-digitated shape, where L is the finger height, *x* is displacement and *g* is gap between top and bottom fingers. Application of normal force (pressure) on the top membrane creates a displacement *x,* which should then change the capacitance C, based on the change in the
overlapping area.

$$C = 2n\frac{\varepsilon (L - x) l}{g}$$

where e is the dielectric constant, ***n*** is number of fingers, g is gap
width, and *l* is length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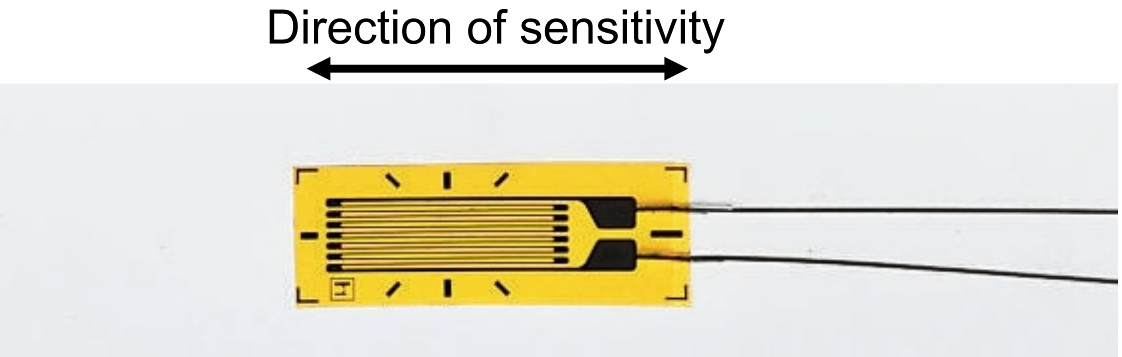
force sensor
laser scanner
(in back)
SICK
laser scanner in front
2 motor wheels

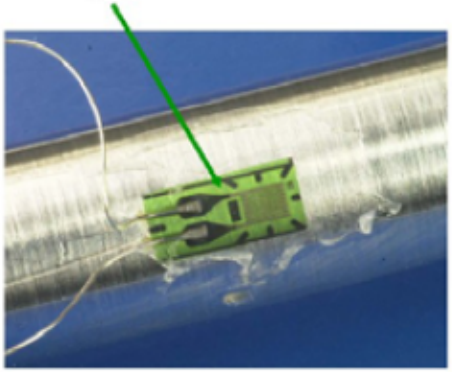
Force Sensors

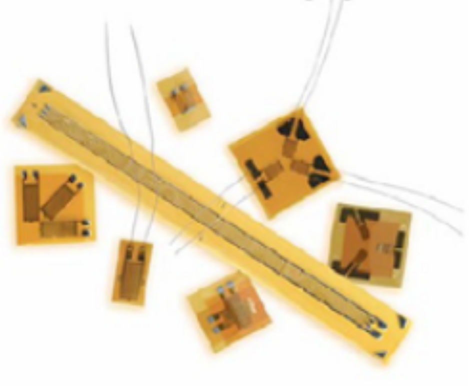
- Strain gauge♪
  - stretching in one direction increases the resistance of the device, while stretching in the other direction has little effect♪
  - can be bonded to a surface to measure strain♪
  - used within load cells and pressure sensors♪

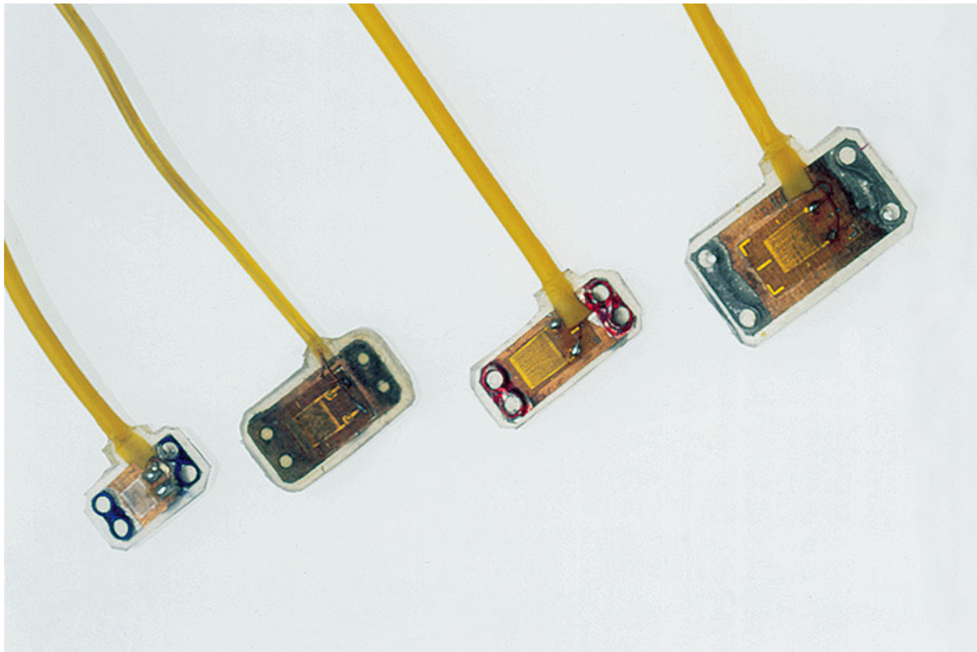


A strain gauge

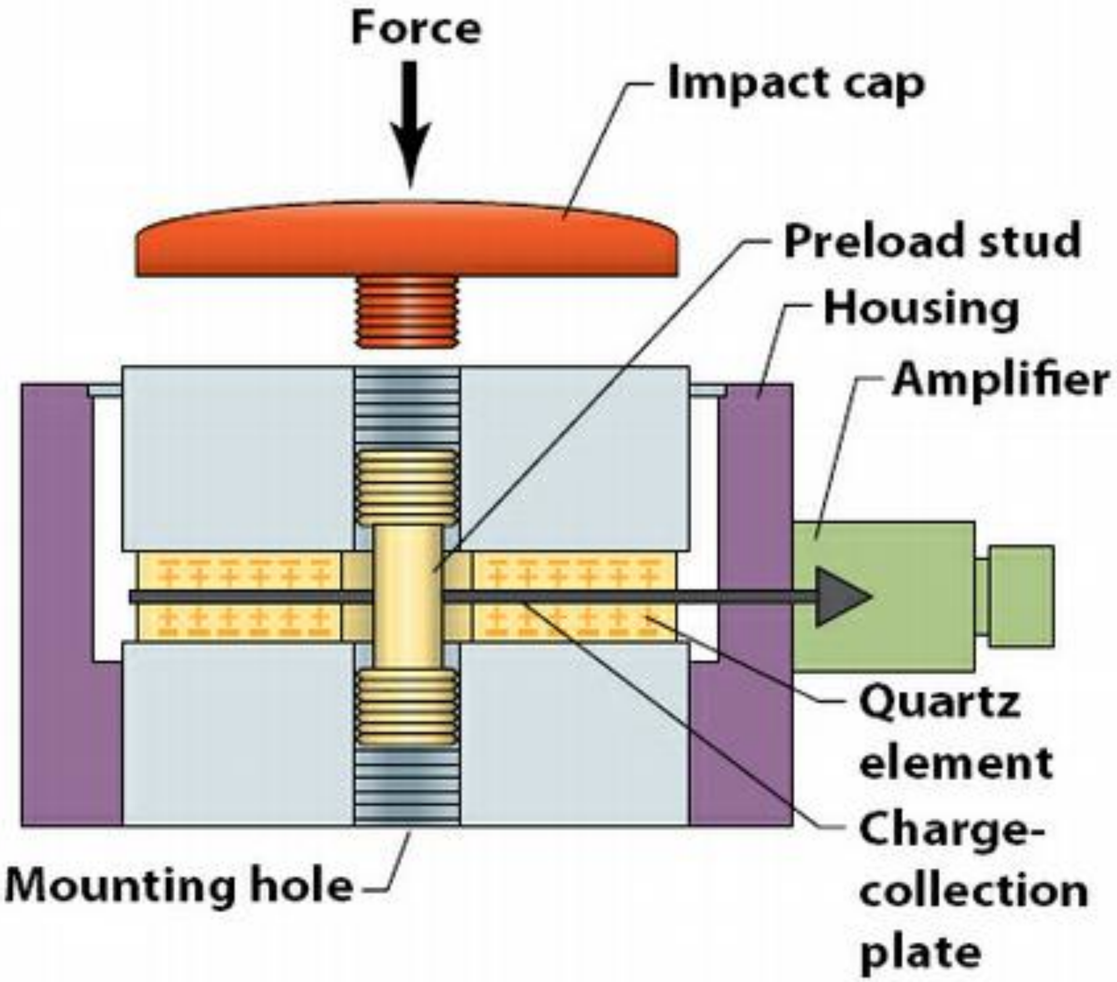
Strain gauge

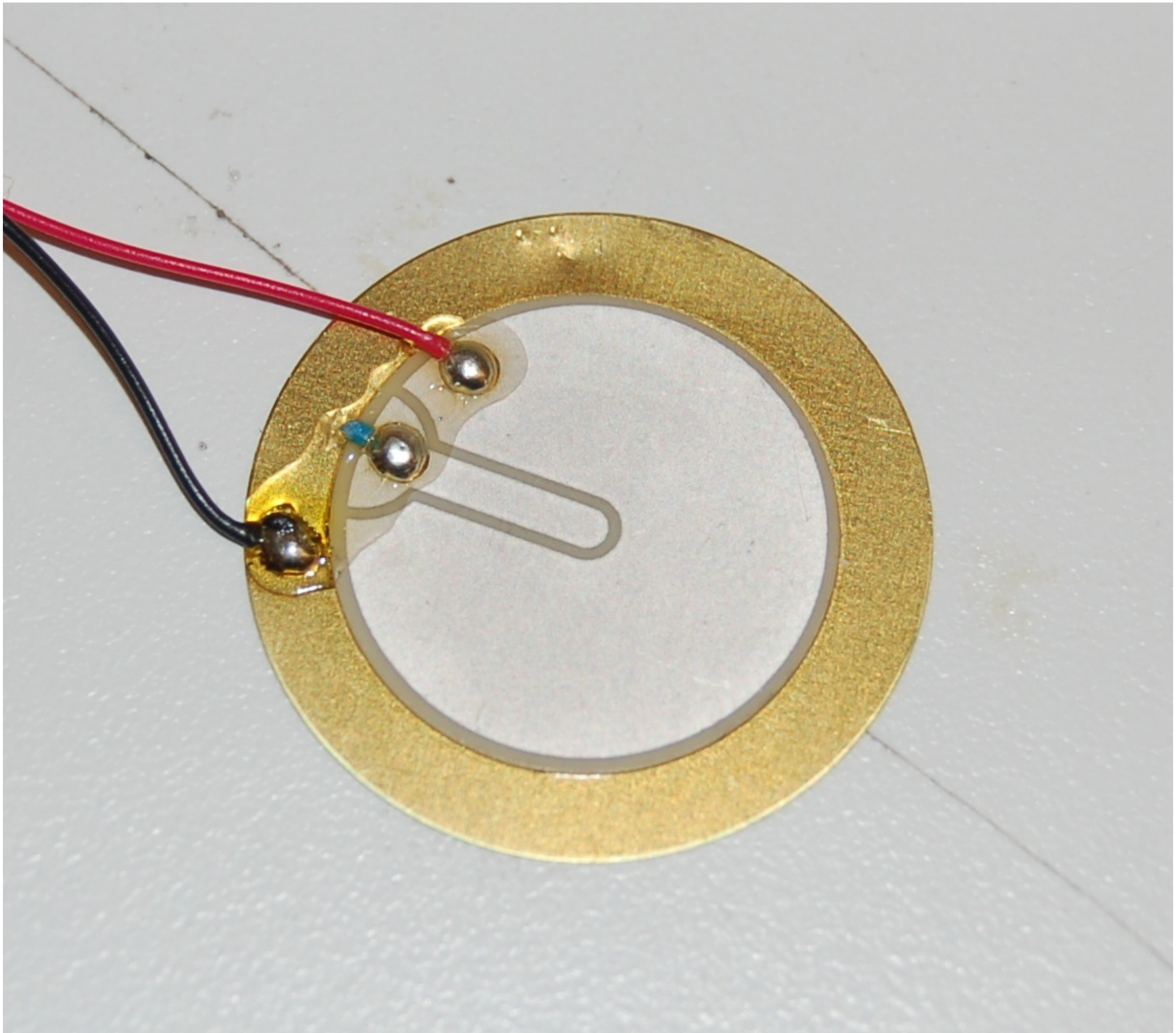

Strain gauge on a rod

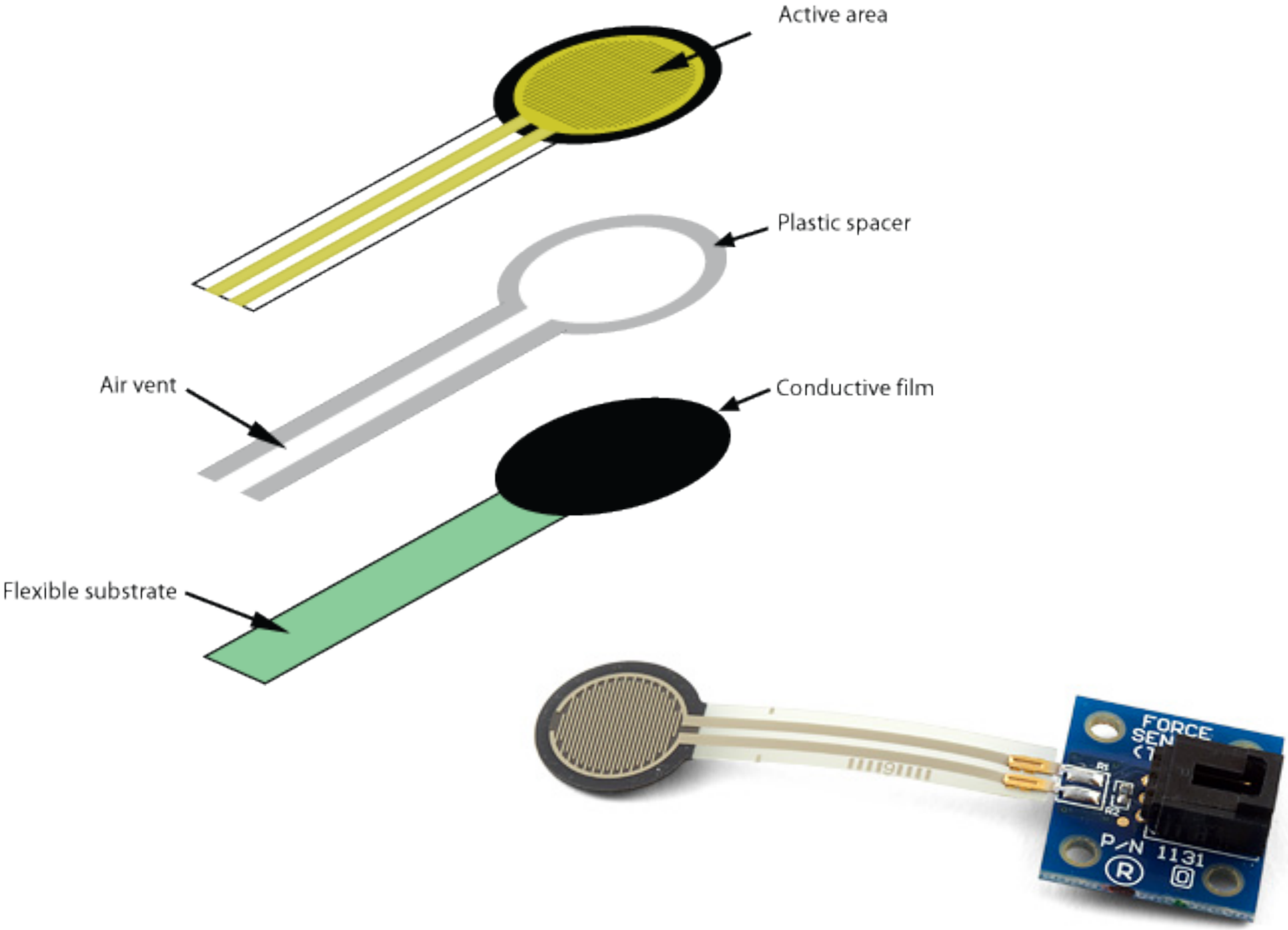

Commercial strain gauges



Piezoelectric force sensor






Active area
Plastic spacer
Air vent
Conductive film
Flexible substrate
FORCE
SEN
P/N 1131

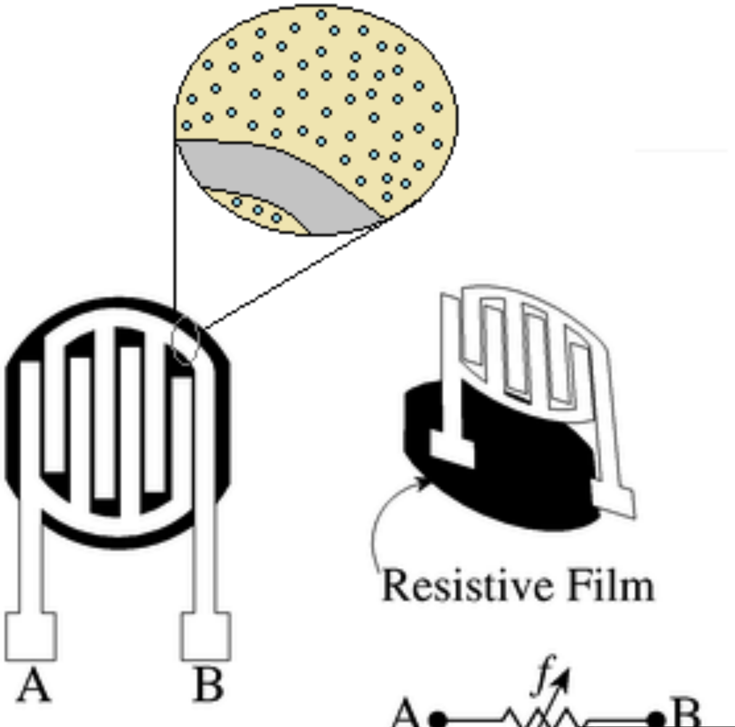
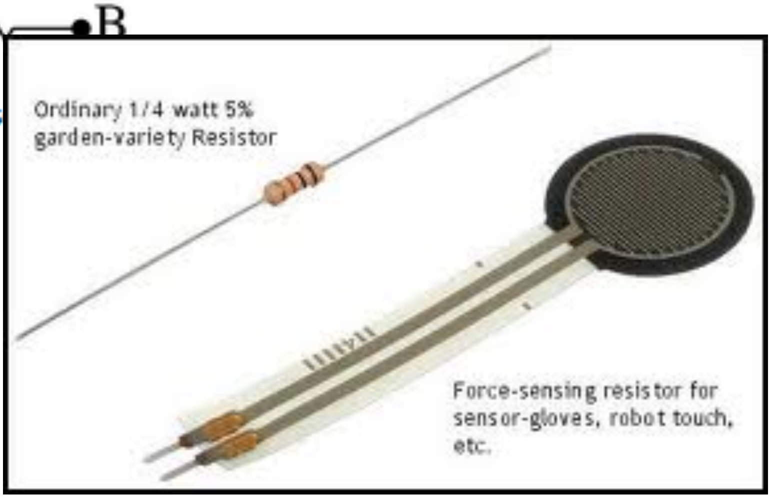
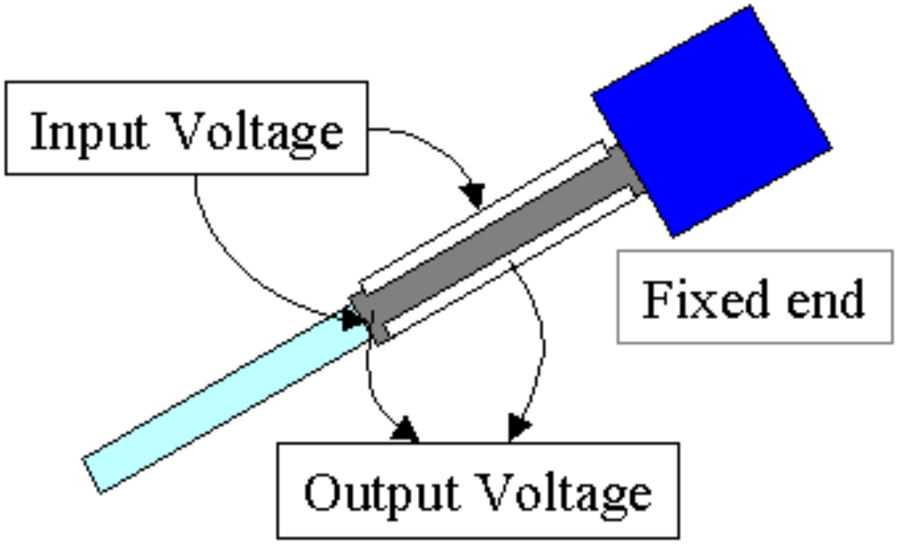
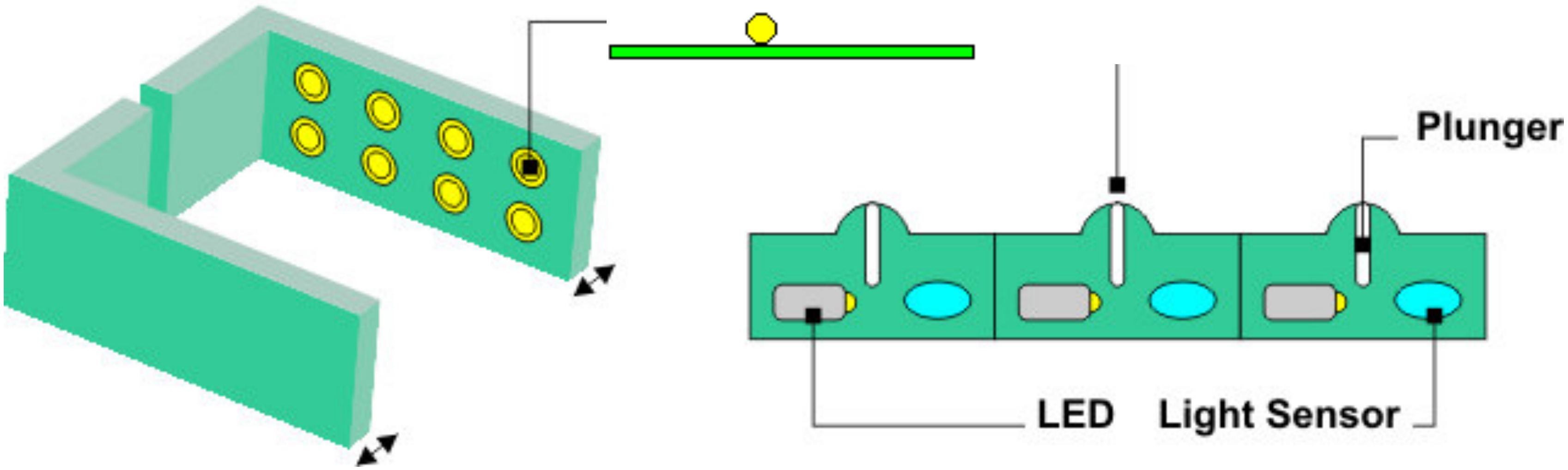


Figure 3.1: Two enmeshed conductors with s




Input Voltage
Fixed end
Output Voltage


Plunger
LED
Light Sensor