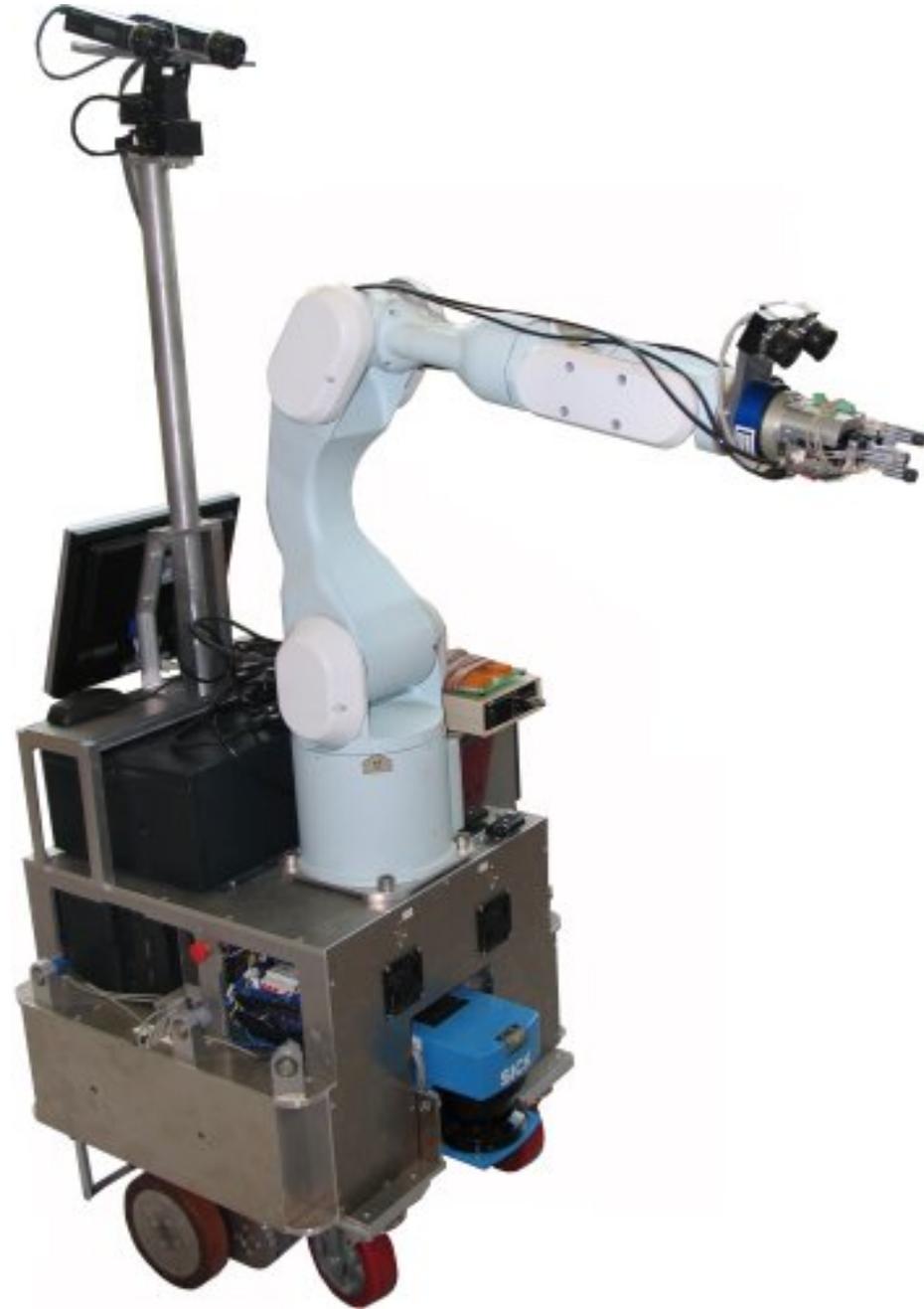
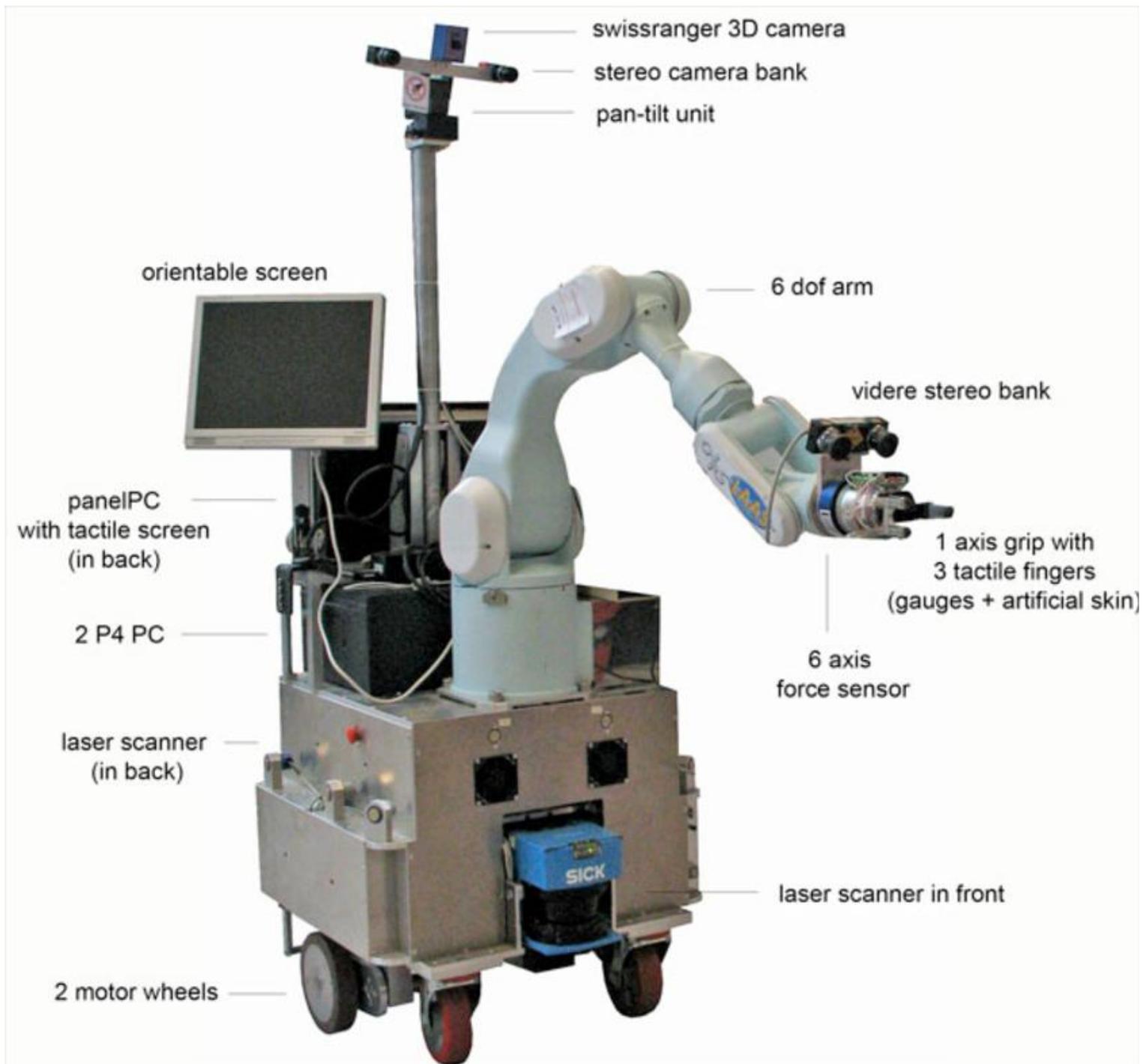


Sensor 1&2 - Displacement and force sensors

ME490A/B

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

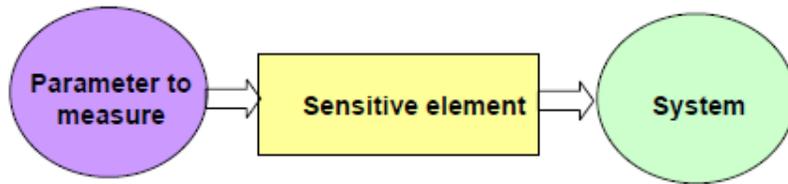




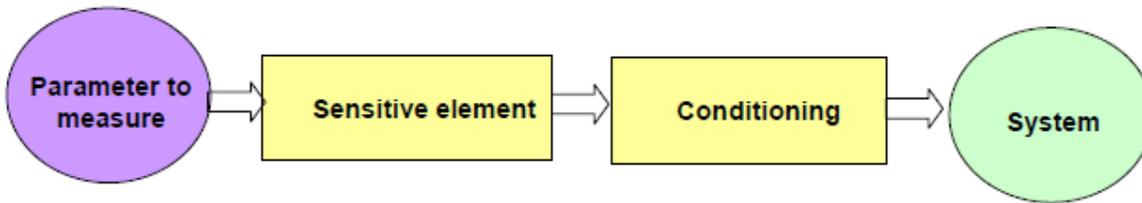
Sensors and Transducers

- 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.

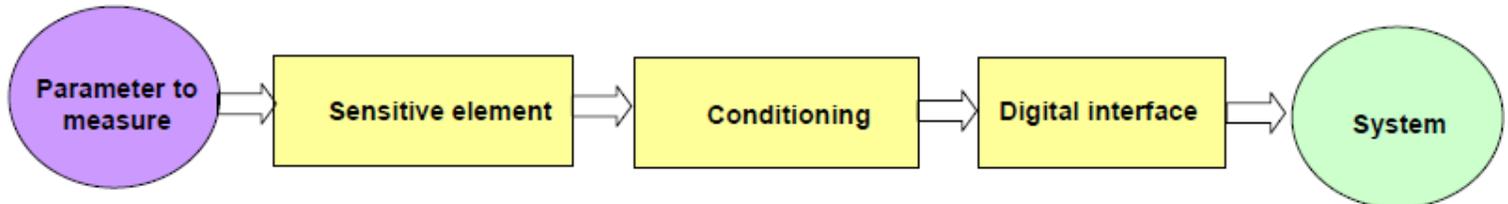
Transducer:



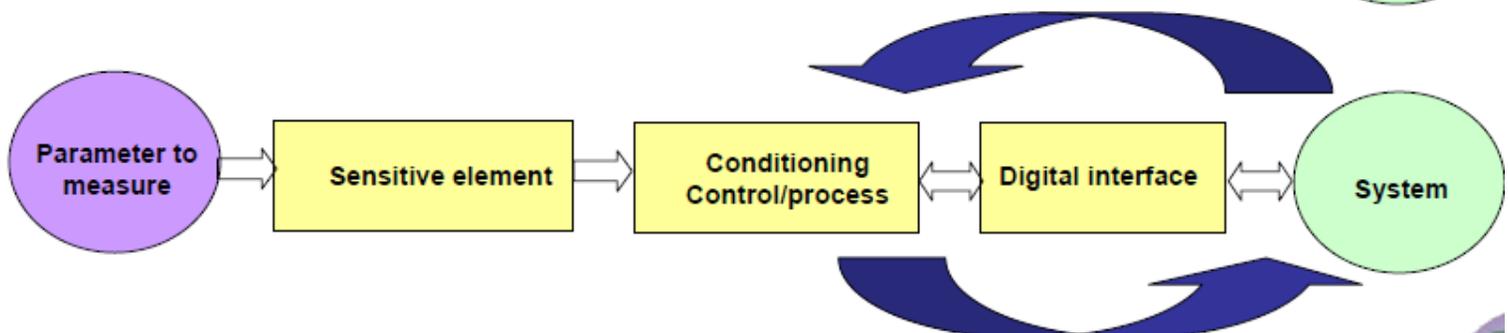
Functional sensor:



Digital sensor:



Smart sensor:

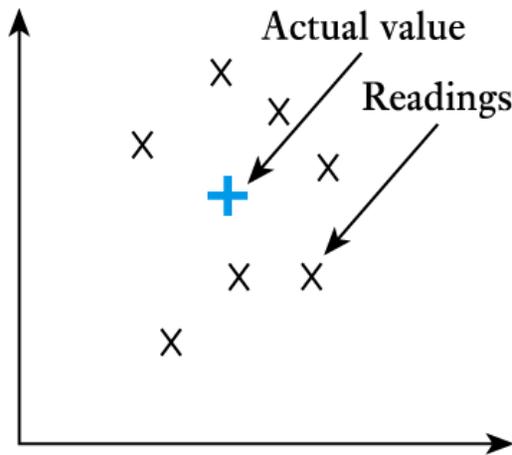


Describing Sensor Performance

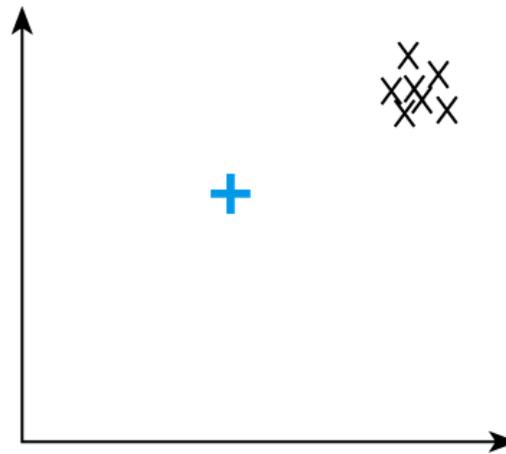
- **Range**♪
 - maximum and minimum values that can be measured♪
- **Resolution or discrimination**♪
 - smallest discernible change in the measured value♪
- **Error**♪
 - difference between the measured and actual values♪
 - random errors♪
 - systematic errors♪
- **Accuracy, inaccuracy, uncertainty**♪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

Precision and accuracy

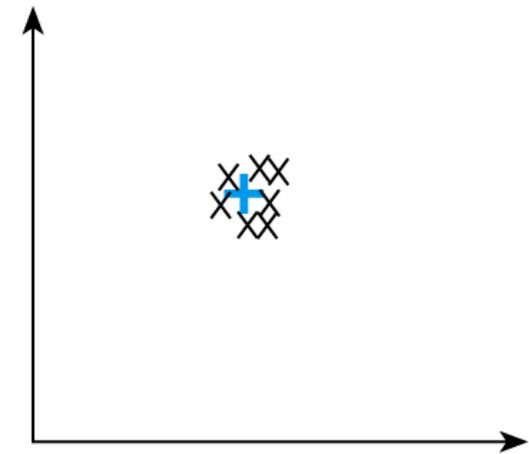
a measure of the lack of random errors (scatter)



(a) Low precision,
low accuracy



(b) High precision,
low accuracy



(c) High precision,
high accuracy

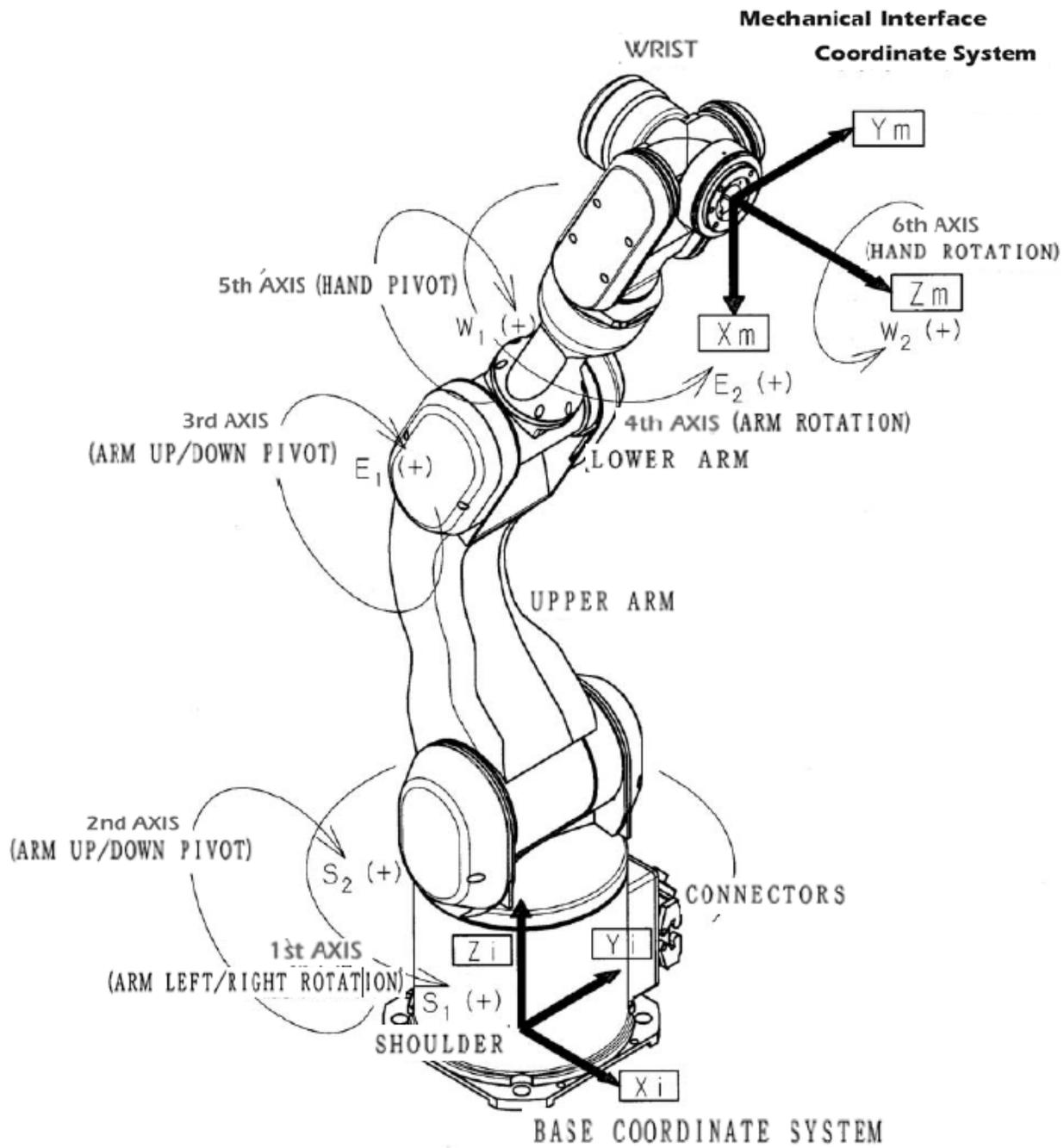
Precision and accuracy♪

- **Linearity**♪

- maximum deviation from a ‘straight–line’ response♪
- normally expressed as a percentage of the full–scale value♪

- **Sensitivity**♪

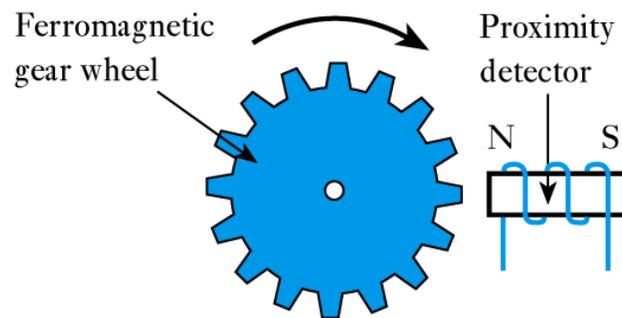
- a measure of the change produced at the output for a given change in the quantity being measured♪



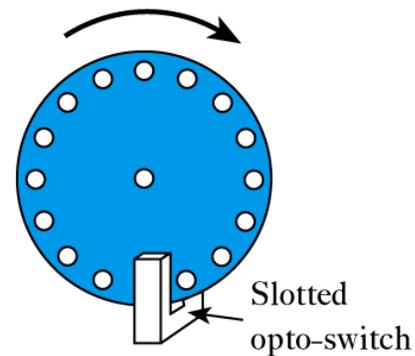
Position sensors

several methods use counting to determine position

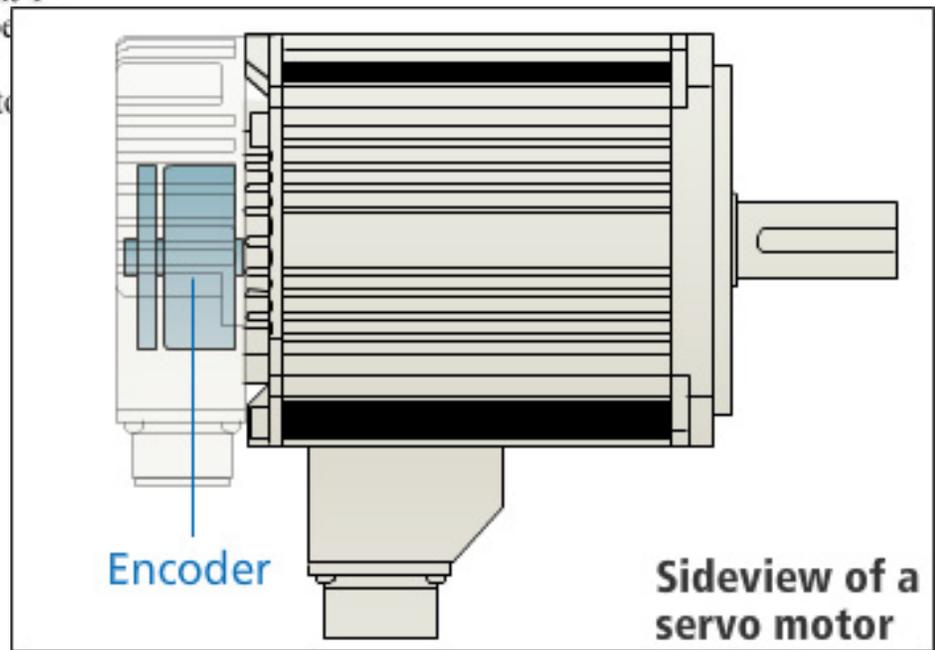
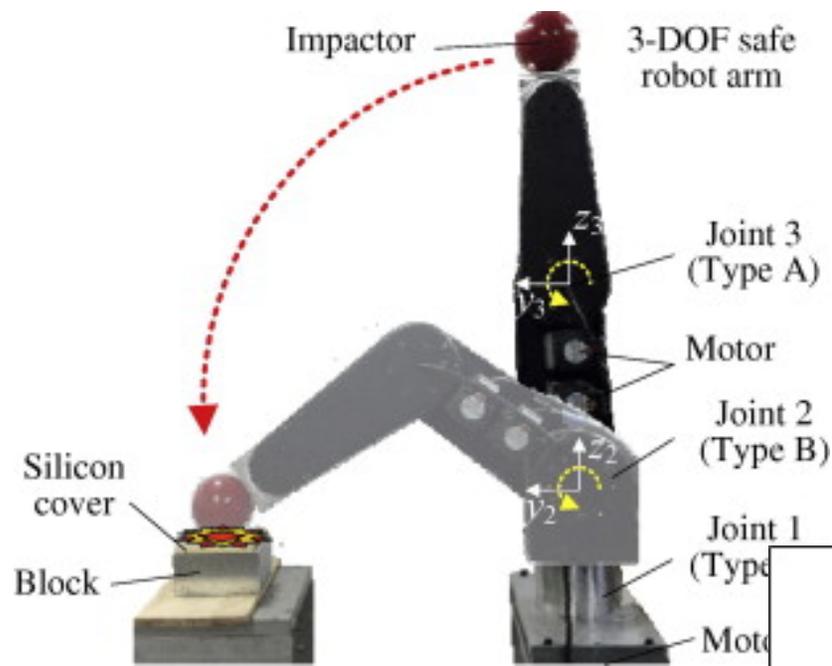
- two examples are given below



Inductive sensor



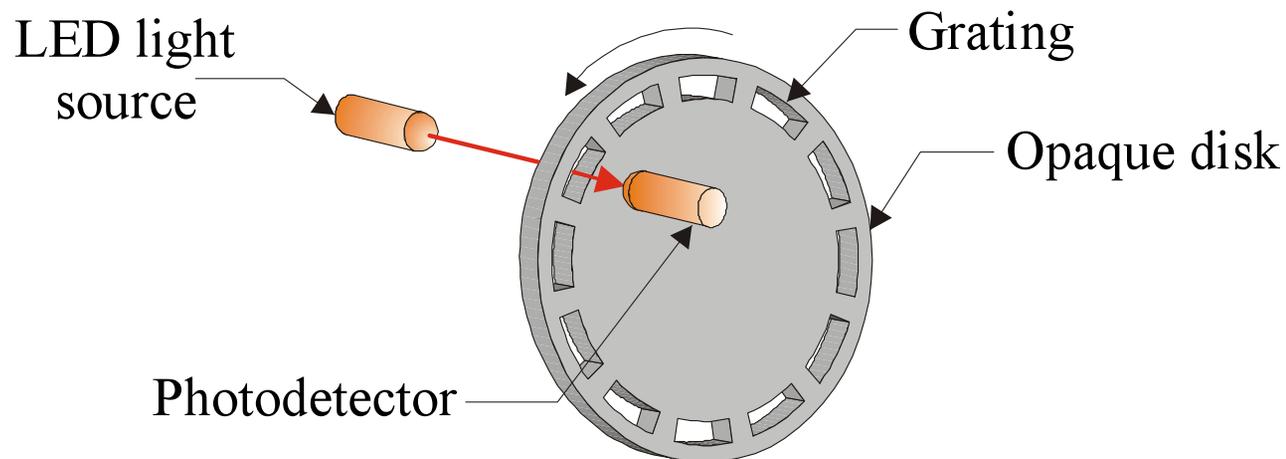
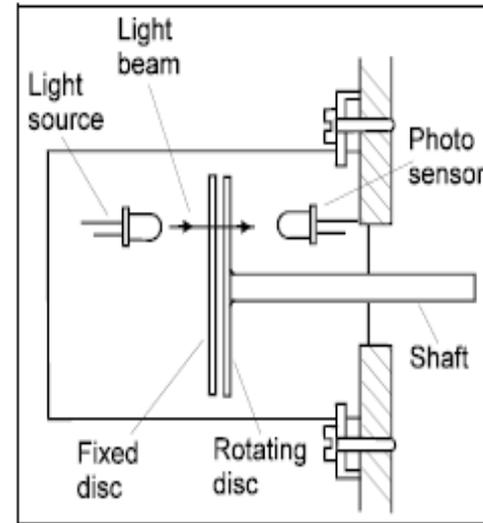
Opto-switch sensor





Incremental Encoders

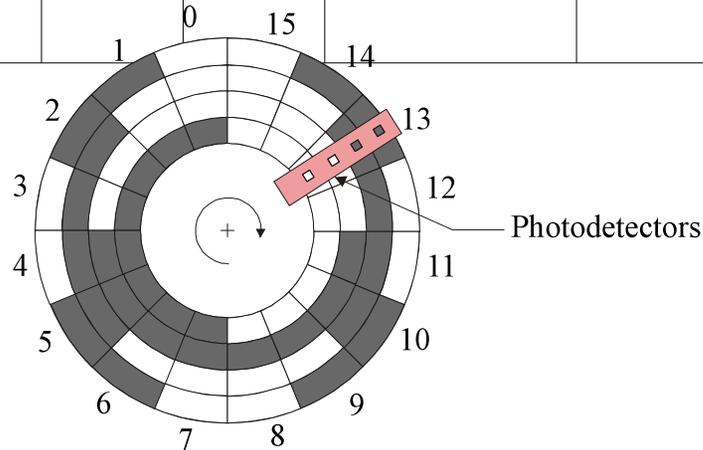
- Digital transducers output data as discrete pulses or coded (digital) information.
- Optical rotary encoders can use *geometric masking*, which allows light to pass through unmasked slits (grating) and be detected by photodetectors on the other side of the disk:



Absolute Encoders

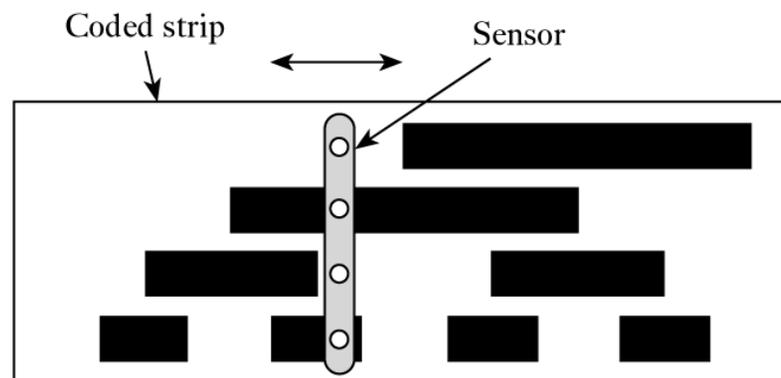
- An absolute encoder, yielding 16 distinct outputs, employing the Gray-coding scheme - The Gray code allows transition of only one bit of data between two consecutive sector numbers: ♪

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



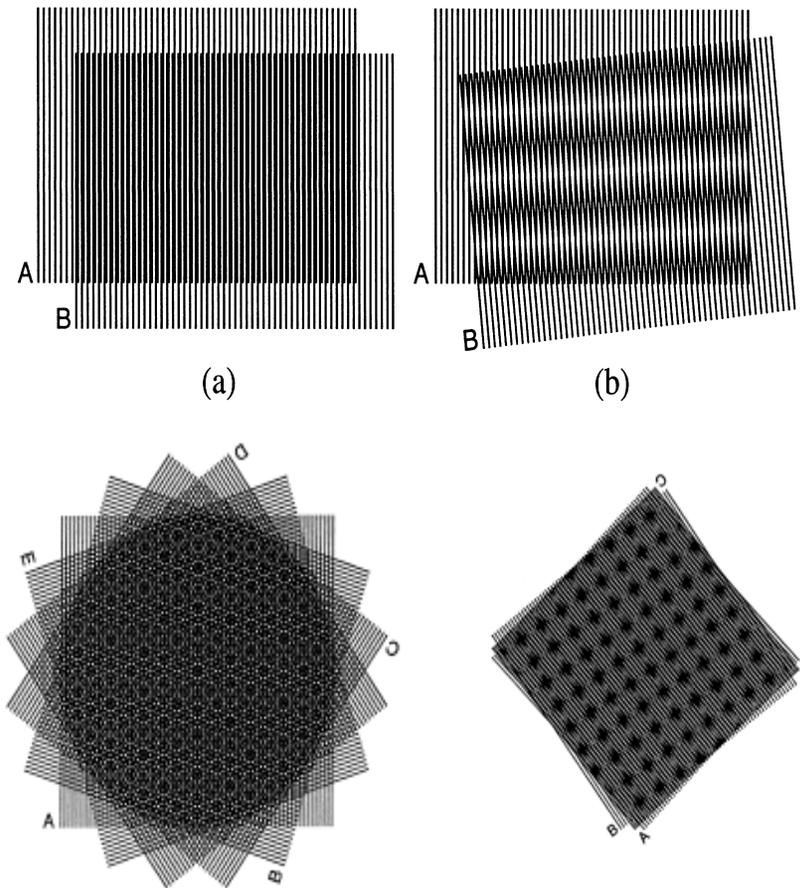
Position encoders

- 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

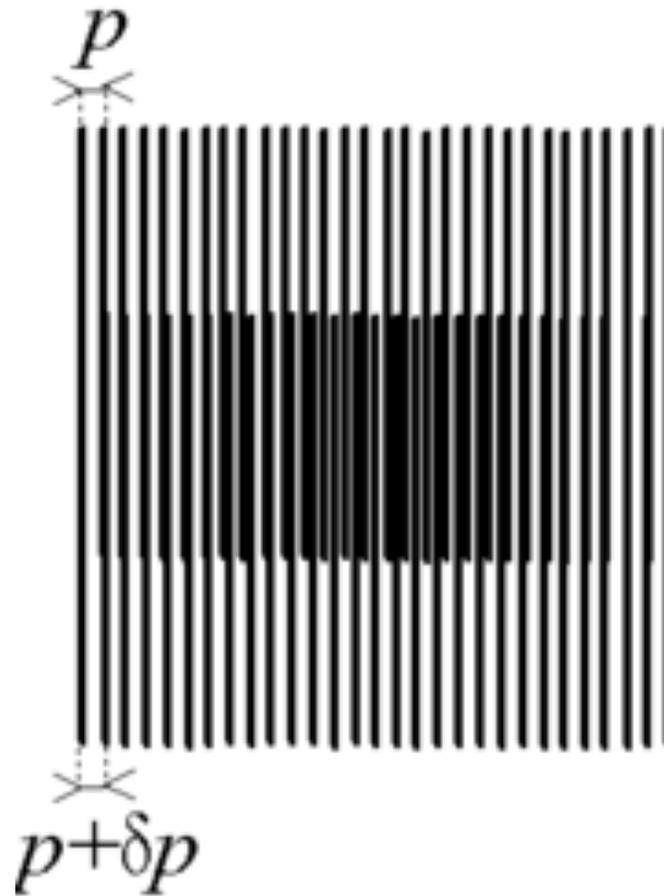


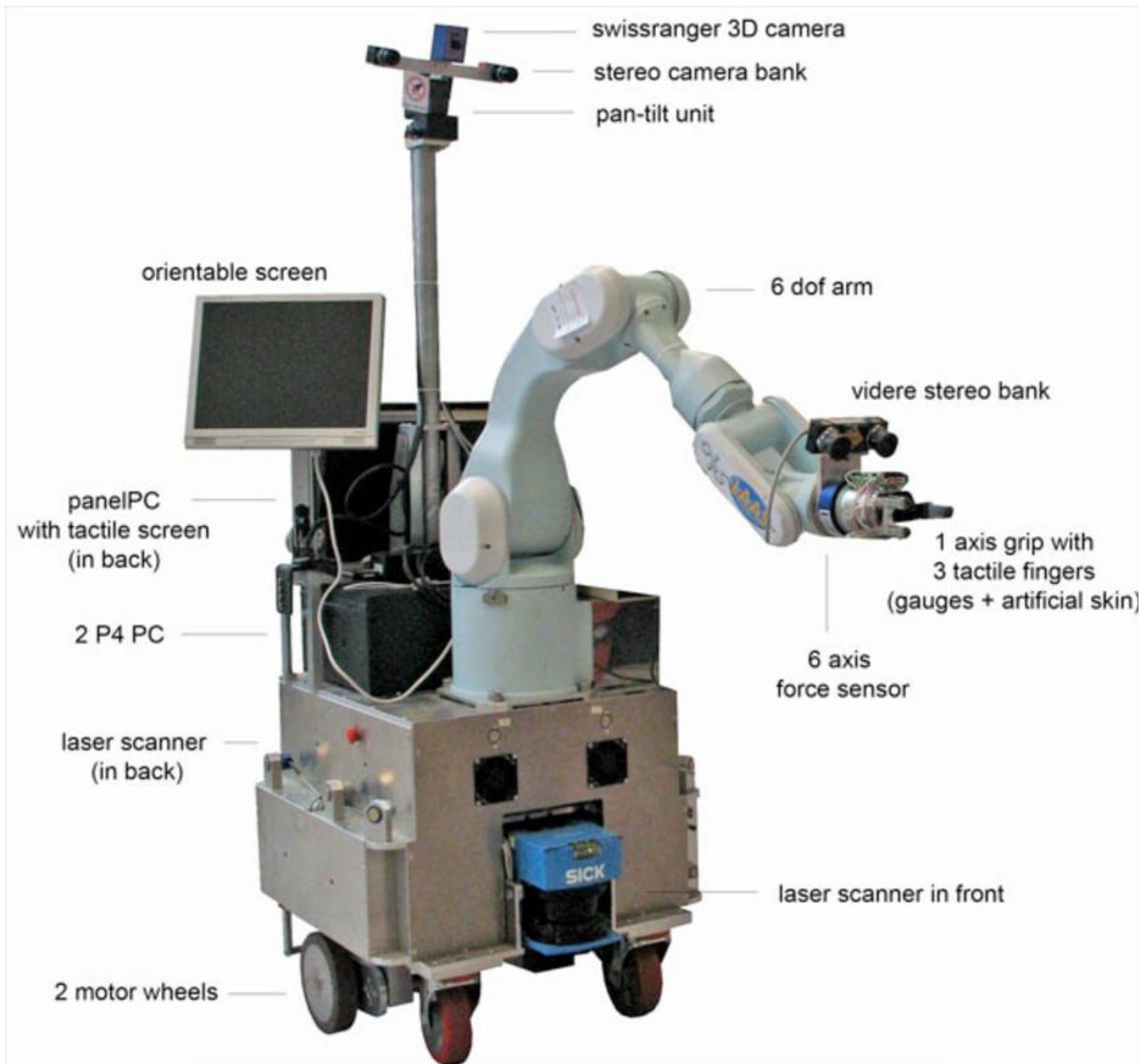
Interferometric encoders

- the moiré effects:
 - The superposition of periodic structures (such as line gratings, dot-screens, etc.) offers a wide range of interesting properties for exploration



Superimpose of two patterns





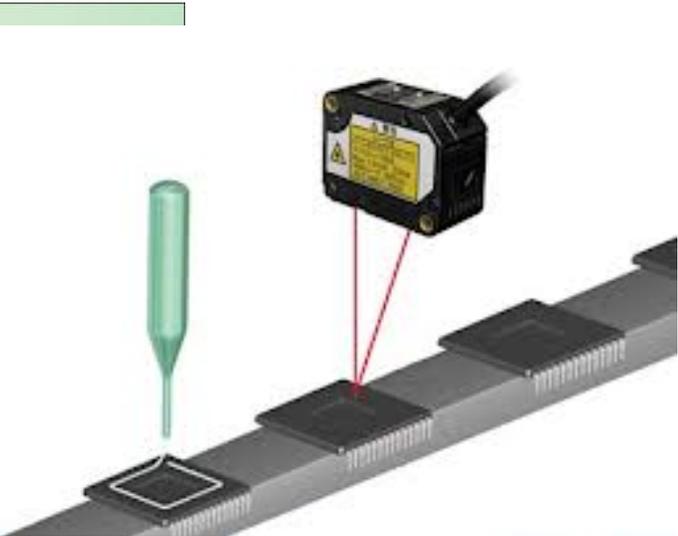
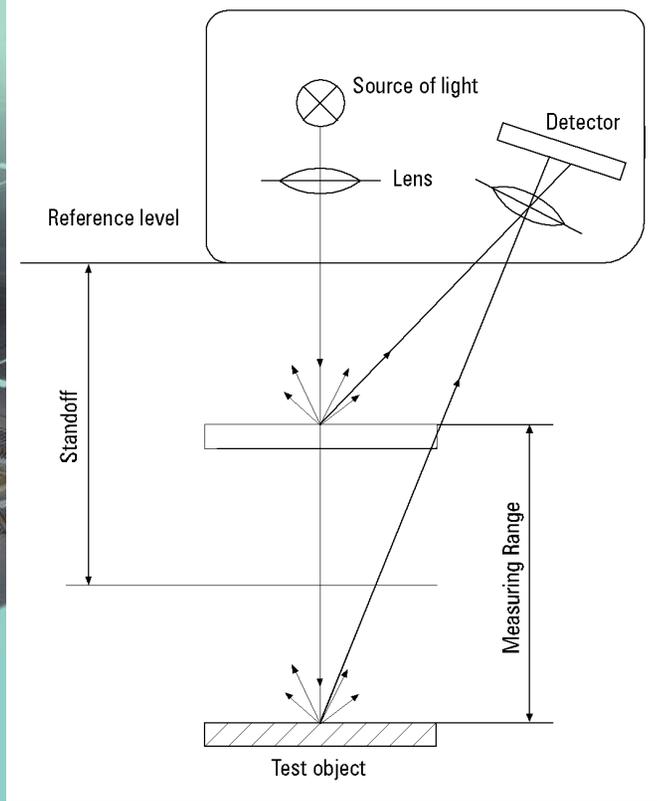
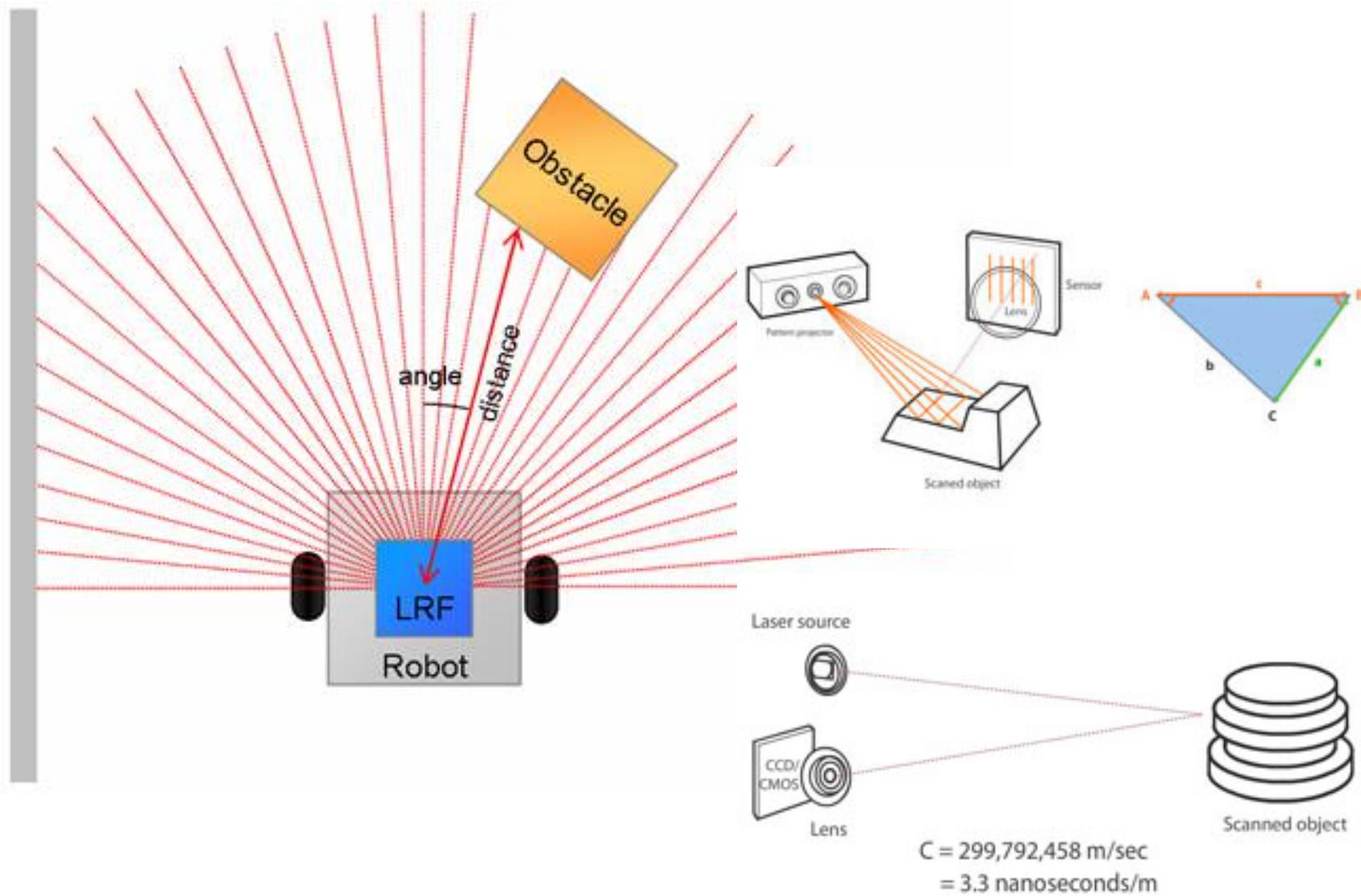
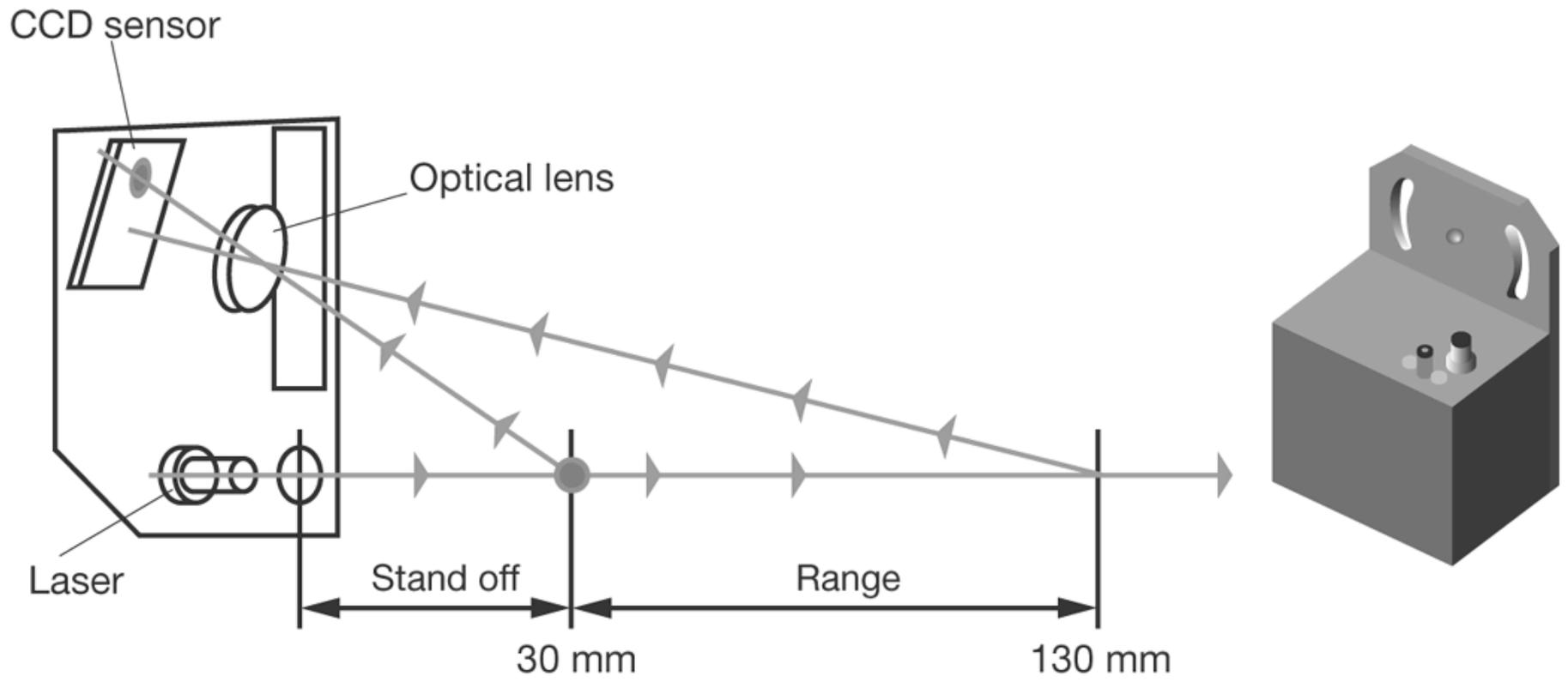


Figure 1 Measurement by a laser triangulations sensor



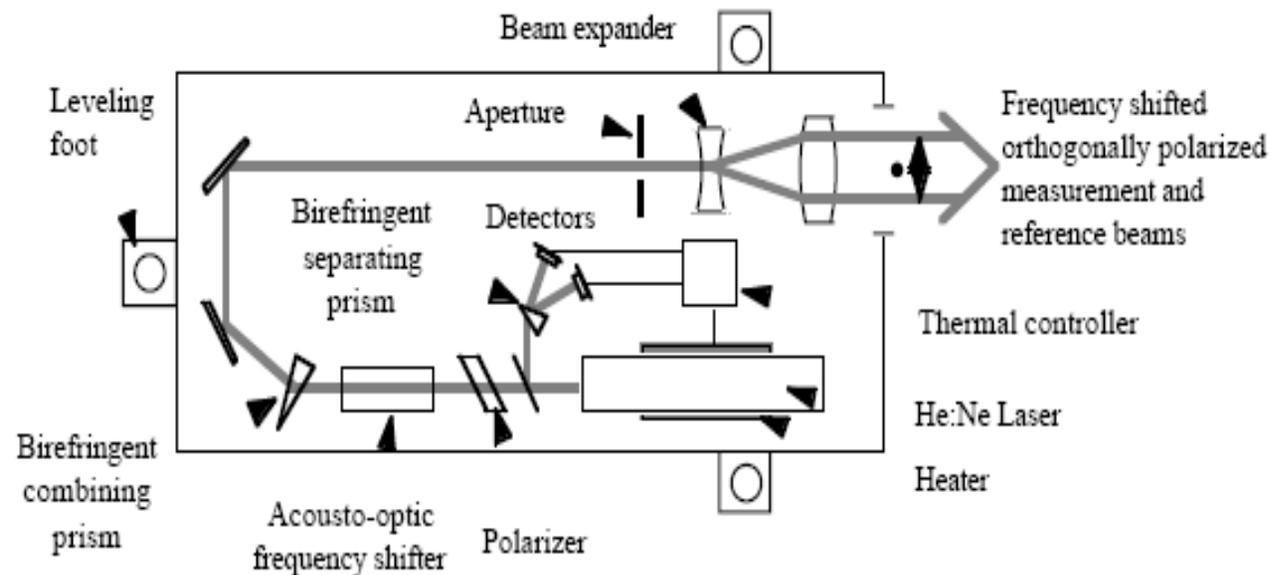
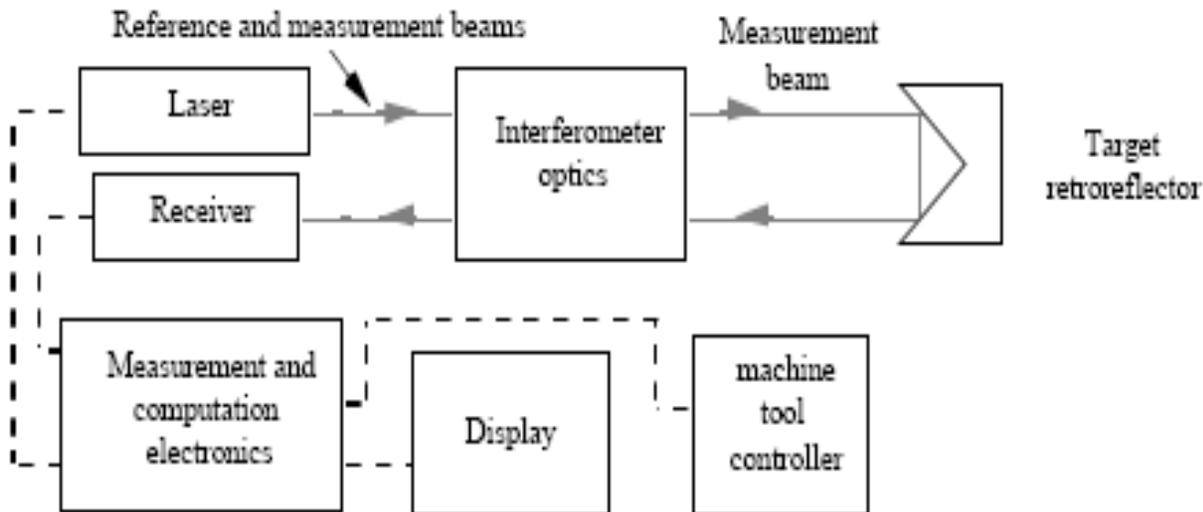




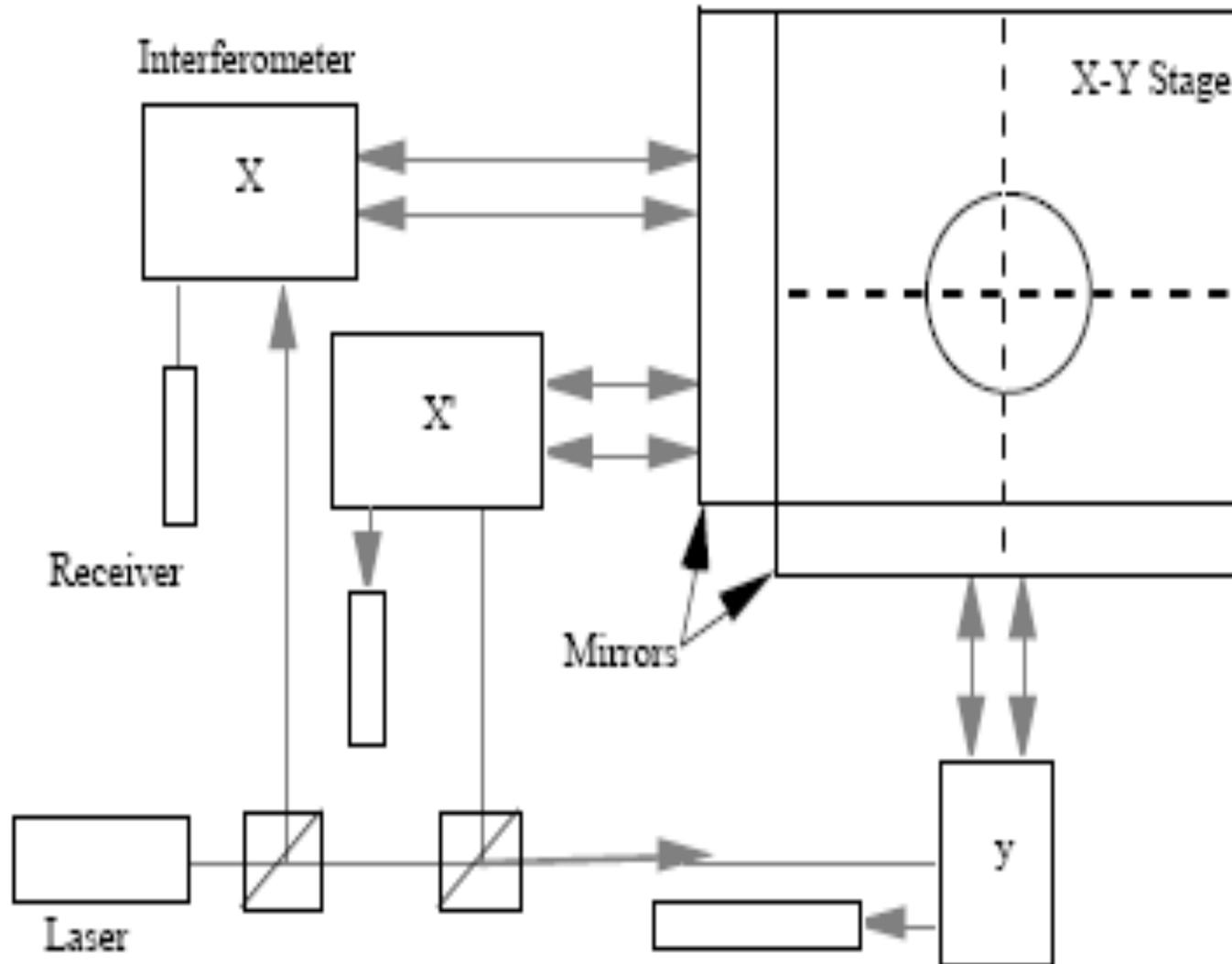
Optical Heterodyne Interferometers

- **Michelson interferometers** count fringes which limits the resolution to about $1/8$.
- **Heterodyne** techniques can be used to achieve two orders of magnitude greater resolution:

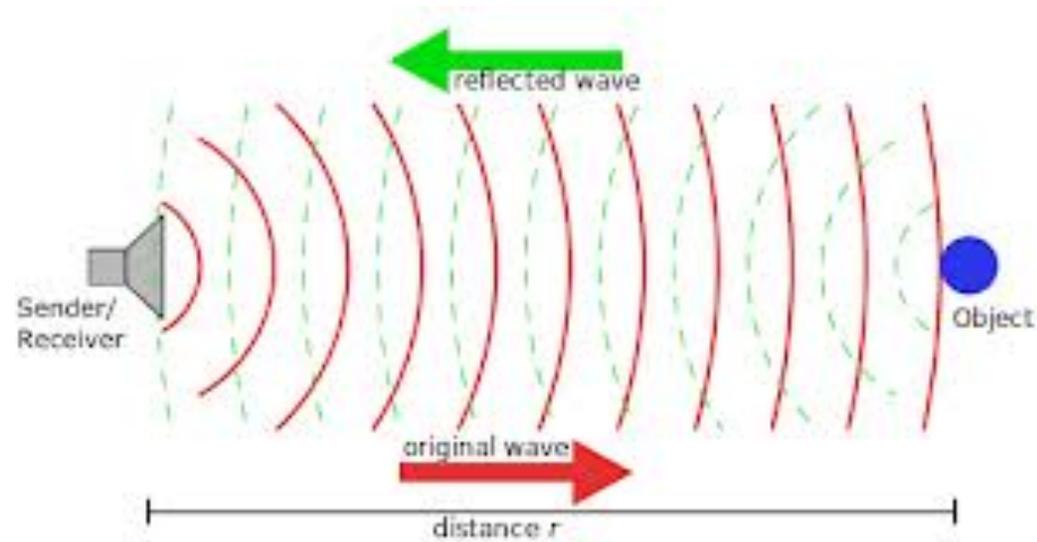
Construction of a laser head used with an Optical Heterodyne Interferometer

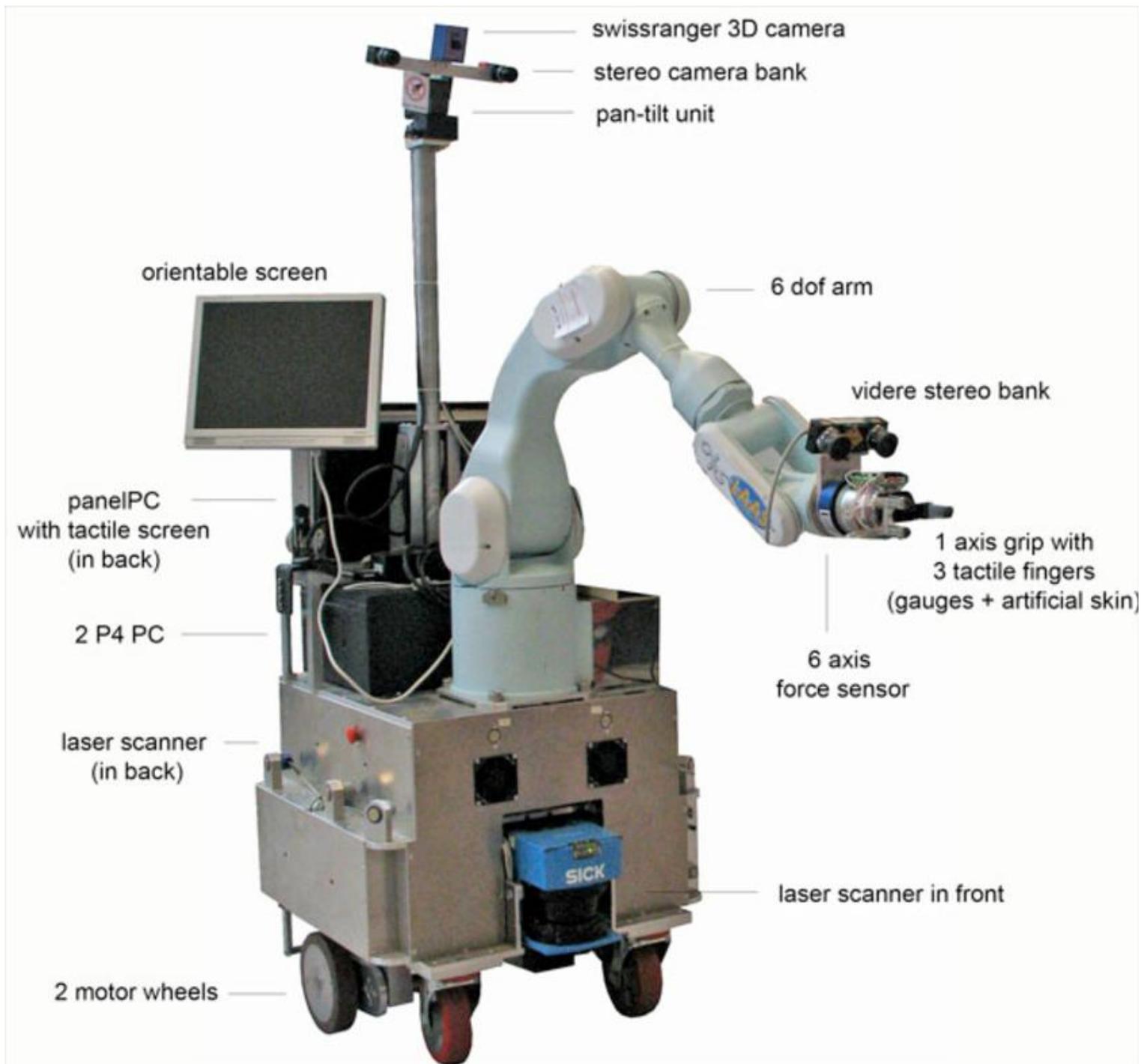


Typical wafer stage metrology using a laser measurement system

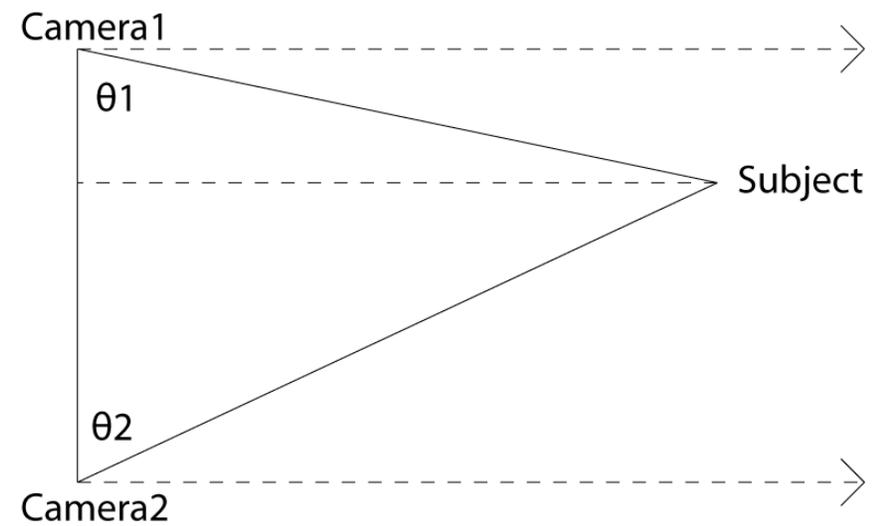


Ultrasound range sensor





Stereo camera sensor



LVDT

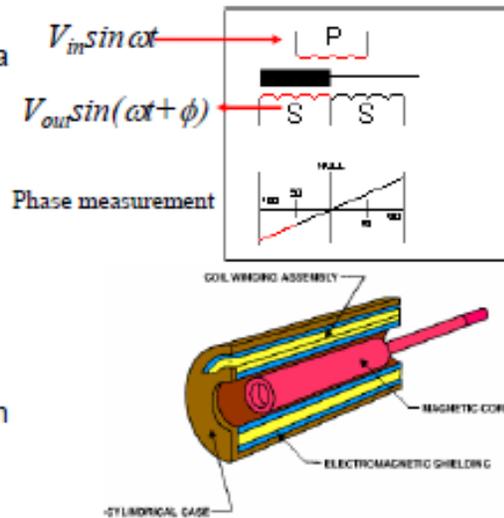
Linear Variable Differential Transformer (LVDT)

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

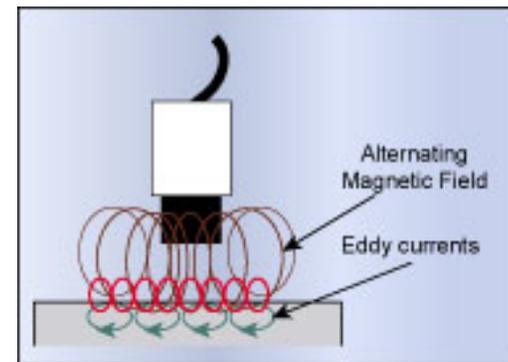
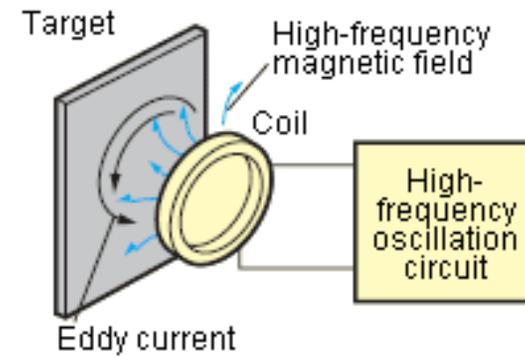


Spring-loaded
Standard for use
In hydraulic cylinders

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).



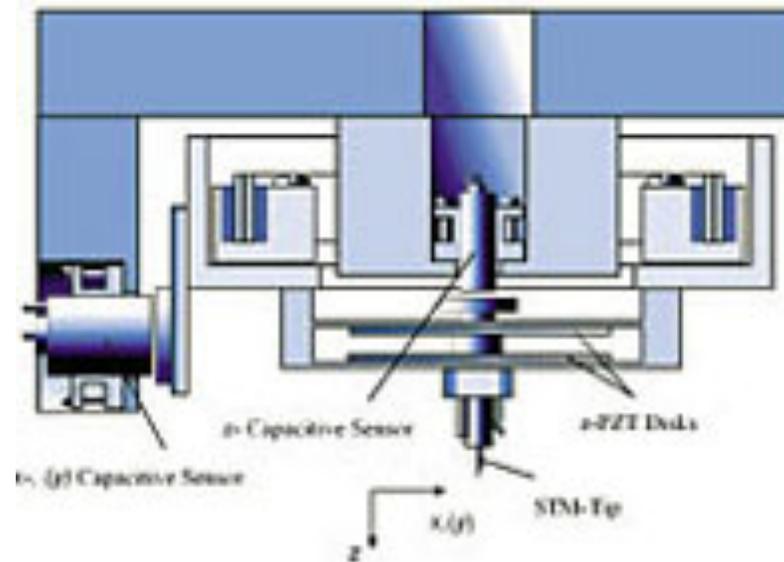
Applications

- 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

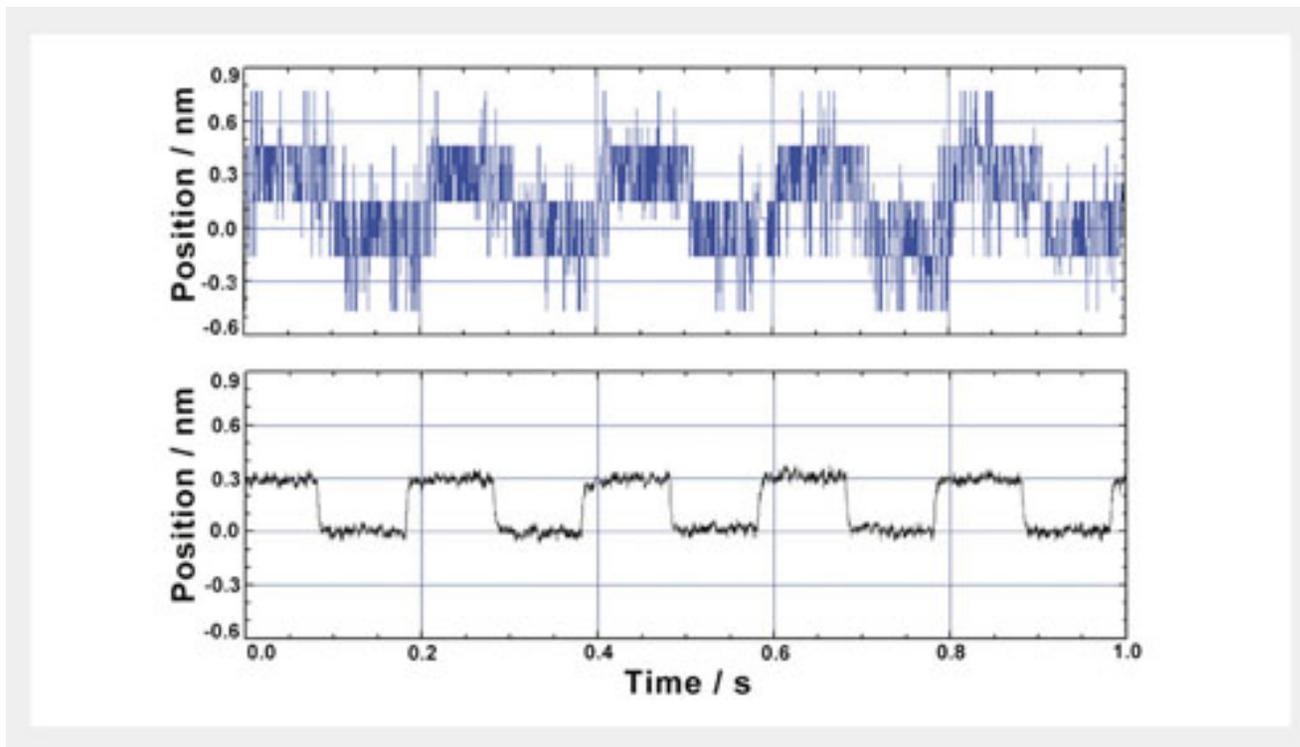


Capacitive position sensors in an ultra-high-accuracy, six-axis nanopositioning system designed by PI for the German Institute of Standards (PTB). Application: scanning microscopy

Applications



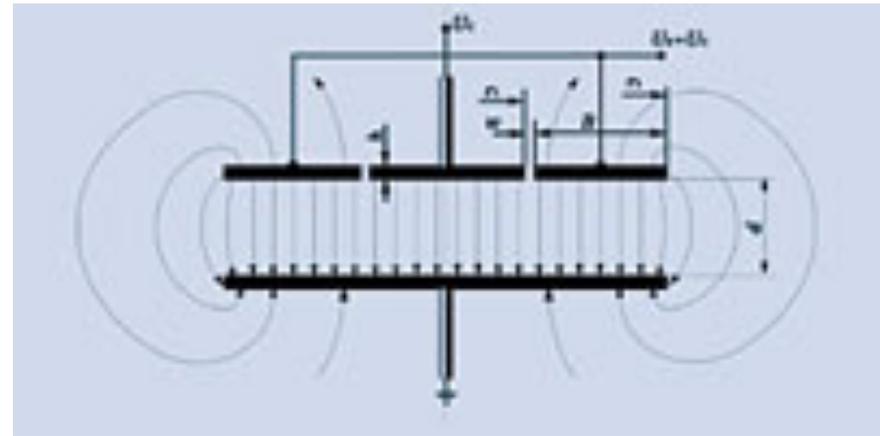
(scanning tunneling microscope) with integrated capacitive position sensors



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

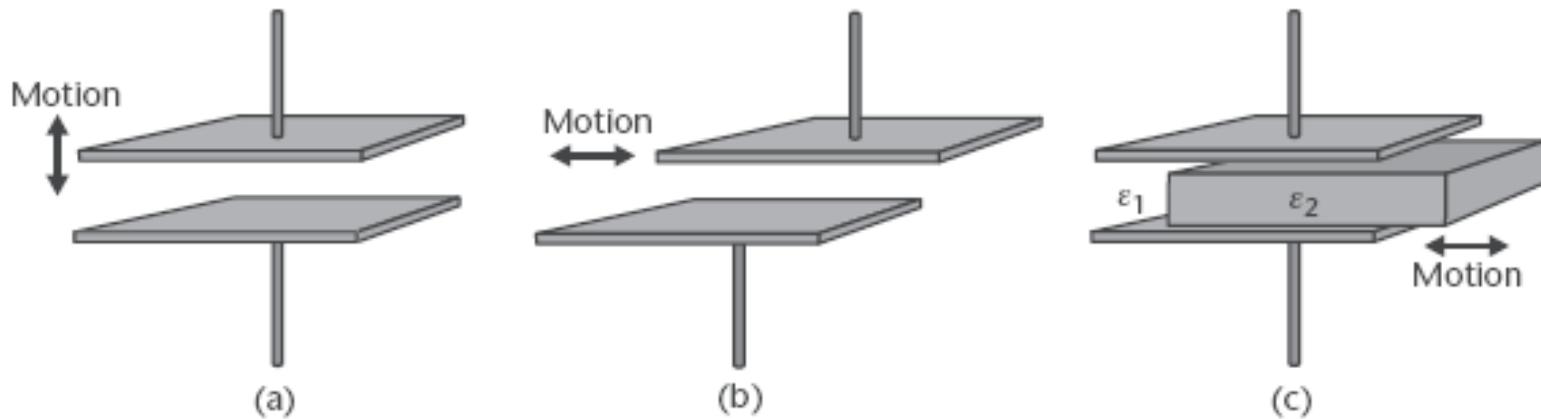


Figure 5.5 Examples of simple capacitance displacement sensors: (a) moving plate, (b) variable area, and (c) moving dielectric.

Differential capacitance sensor

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

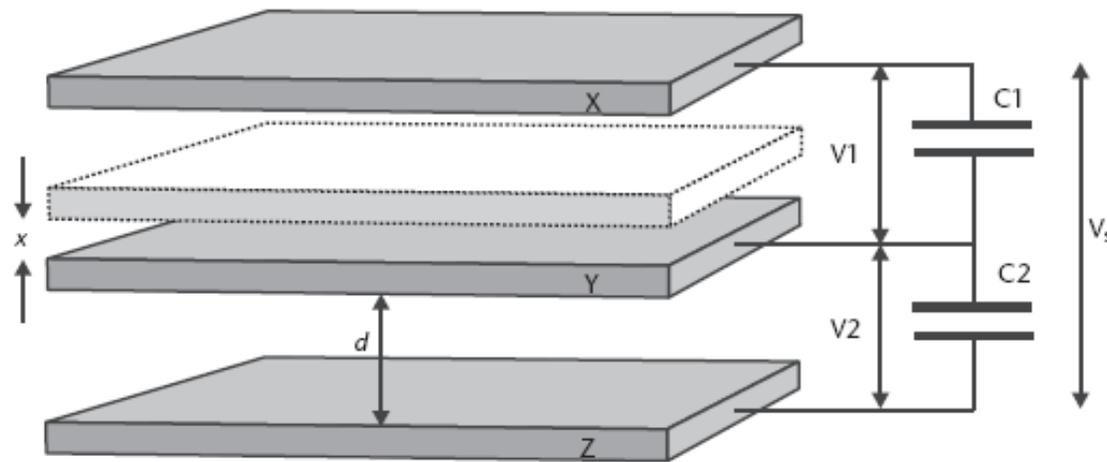
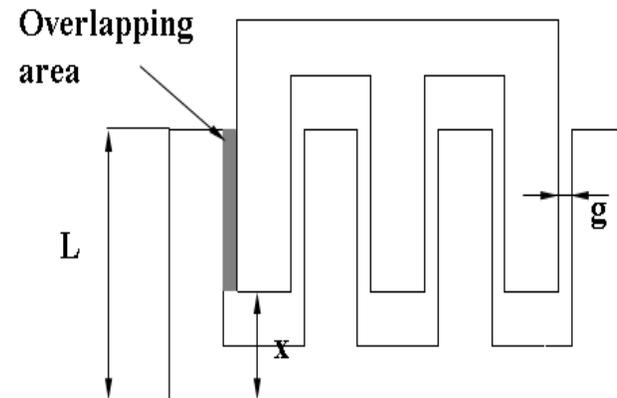
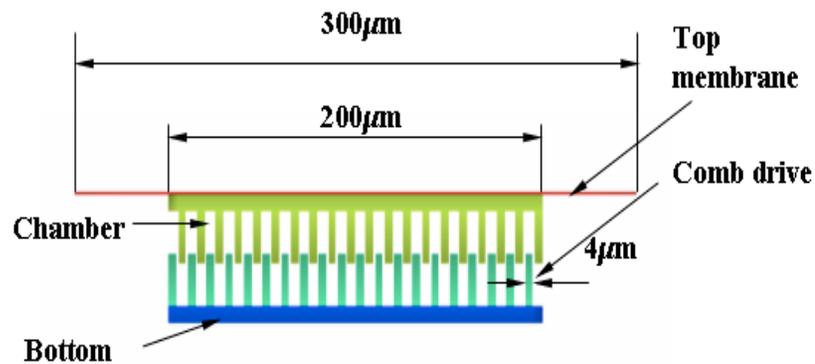


Figure 5.6 A differential capacitance sensor.

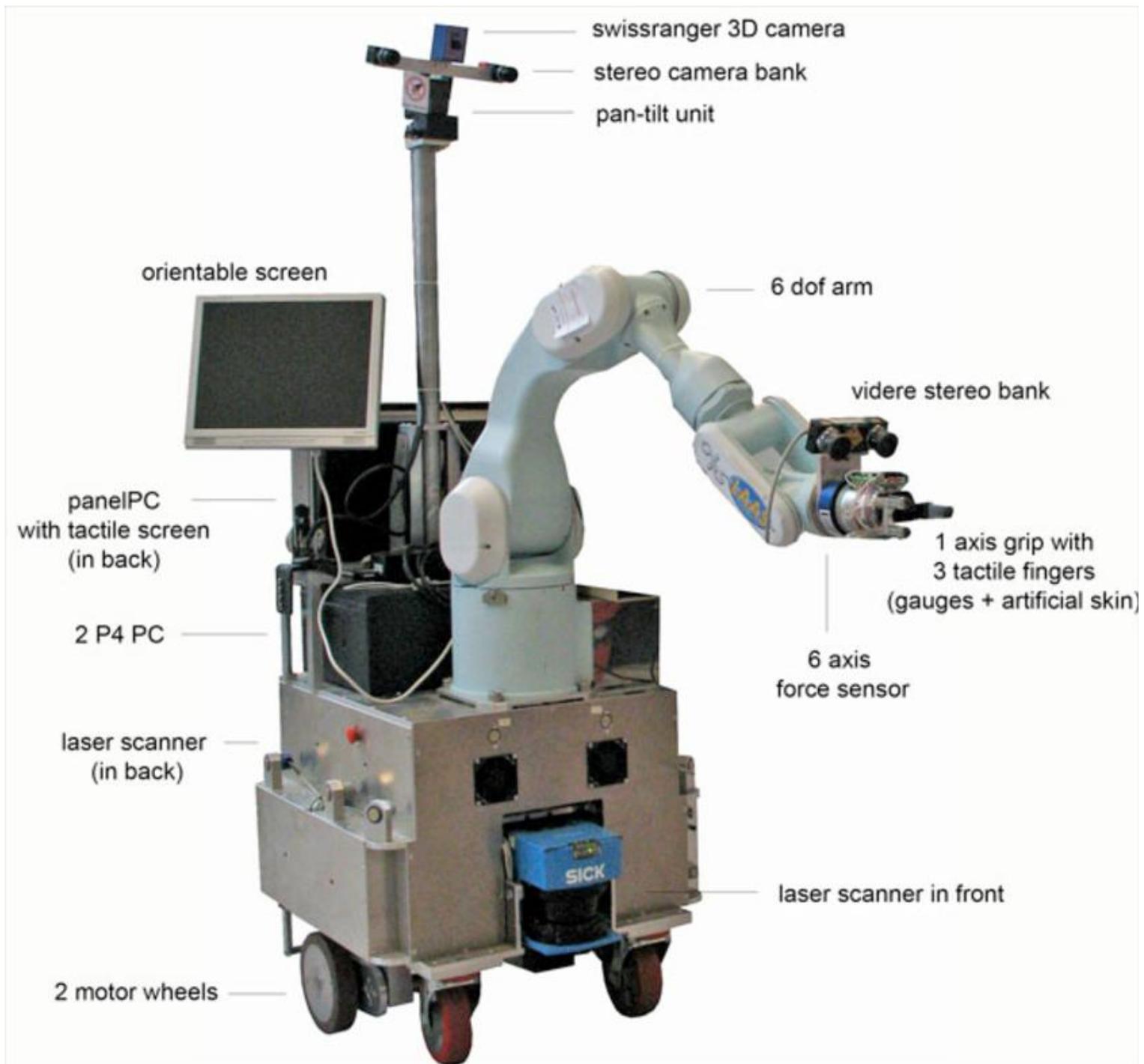
Comb-drive capacitance sensor



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.

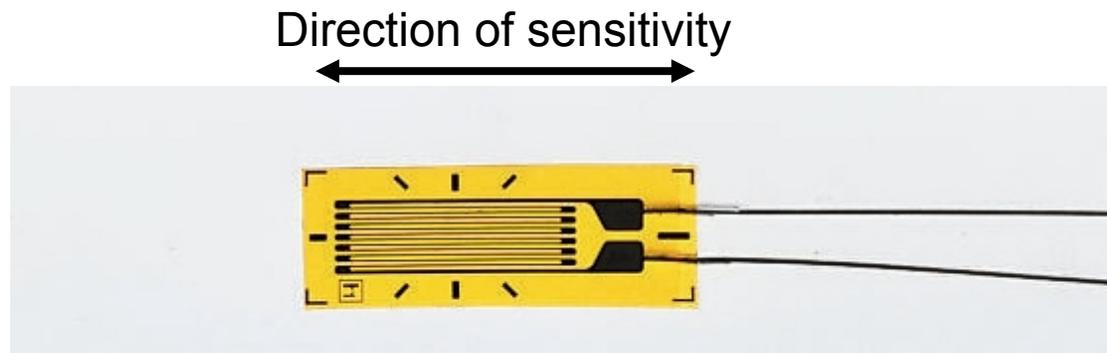
$$C = 2n \frac{\epsilon(L-x)l}{g}$$

where ϵ is the dielectric constant, n is number of fingers, g is gap width, and l is length



Force Sensors

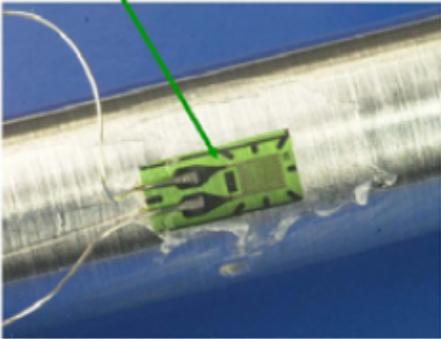
- Strain gauge♪
 - stretching in one direction increases the resistance of the device, while stretching in the other direction has little effect♪
 - can be bonded to a surface to measure strain♪
 - used within load cells and pressure sensors♪



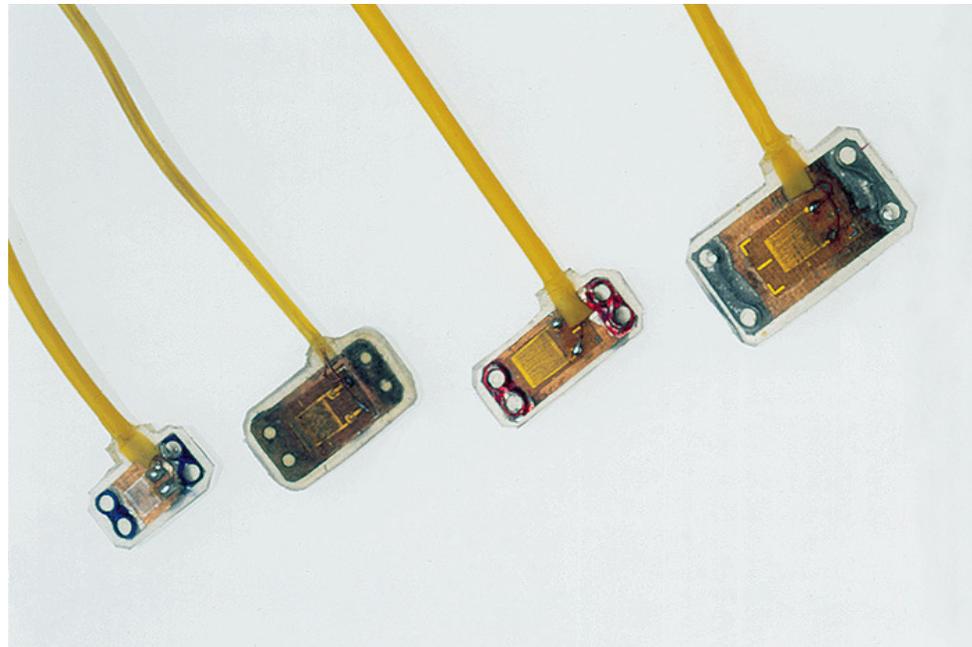
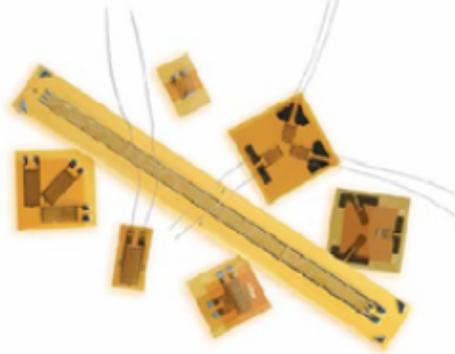
A strain gauge

Strain gauge

Strain gauge on a rod

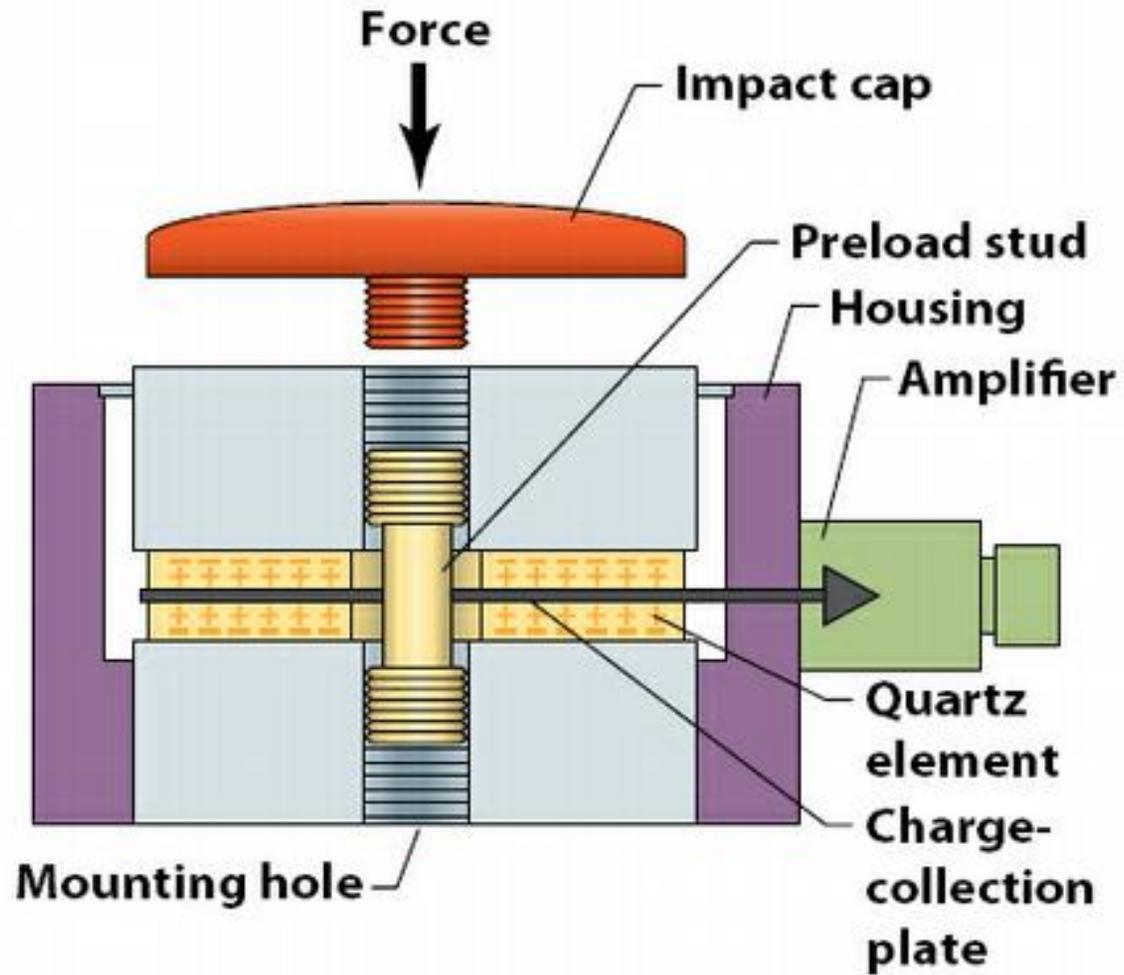


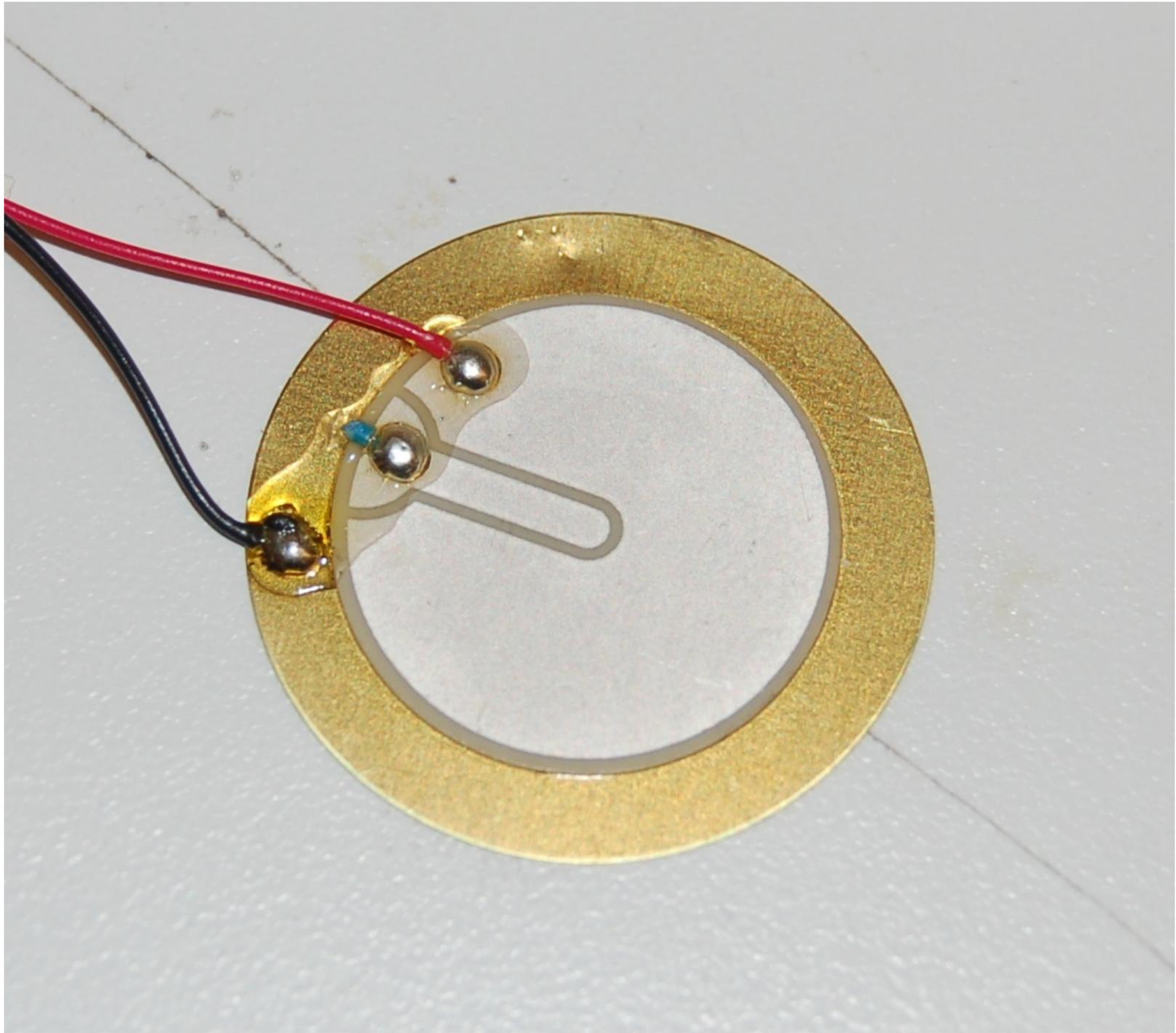
Commercial strain gauges

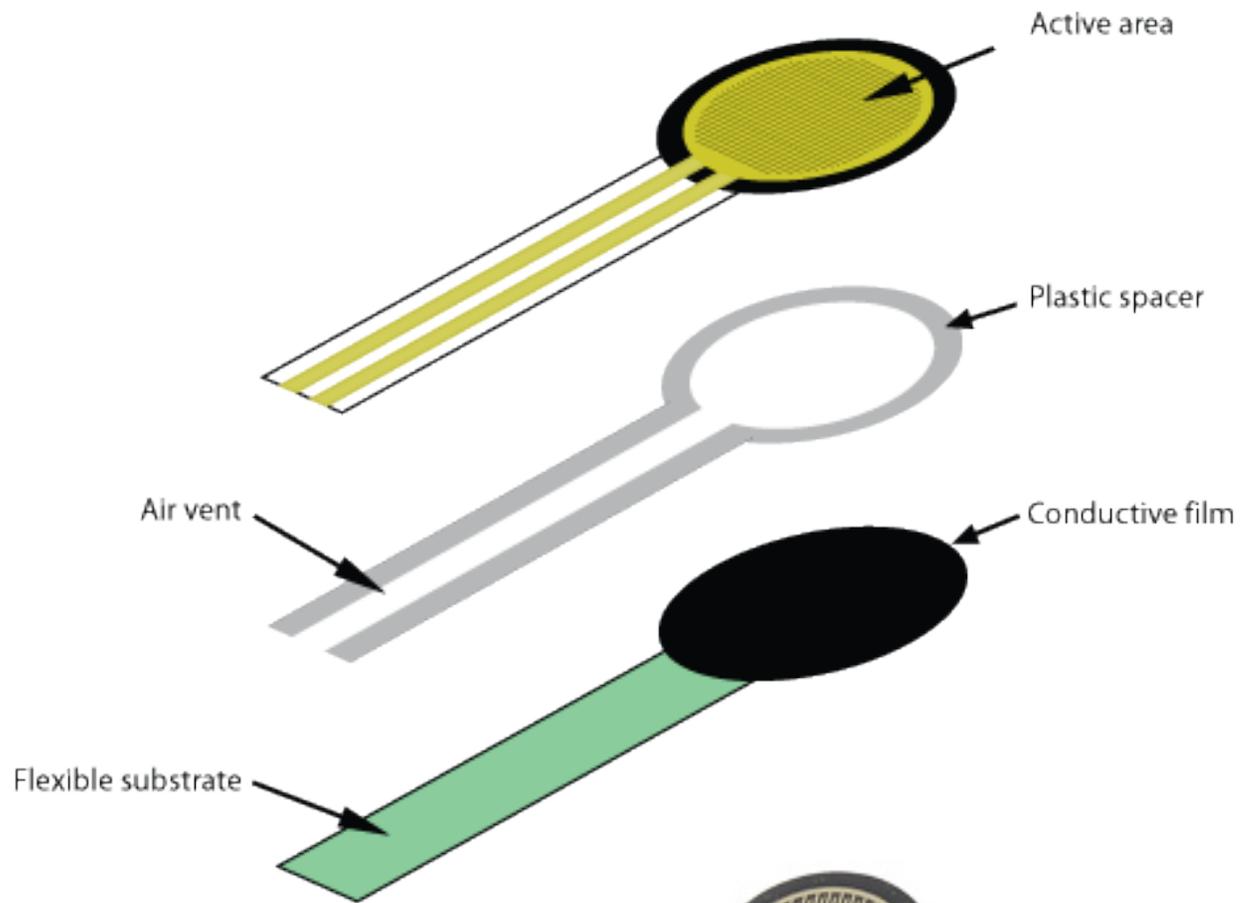




Piezoelectric force sensor







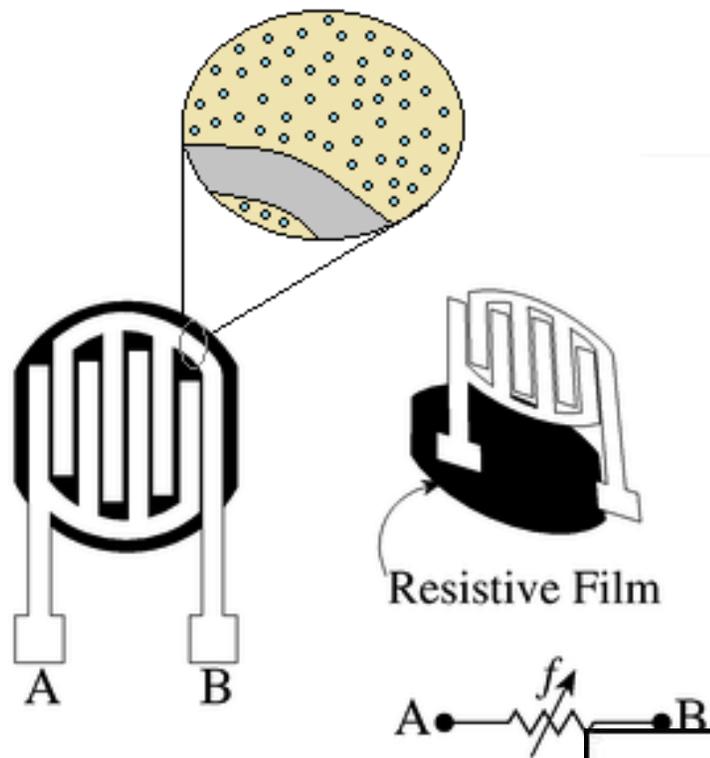


Figure 3.1: Two enmeshed conductors with s

