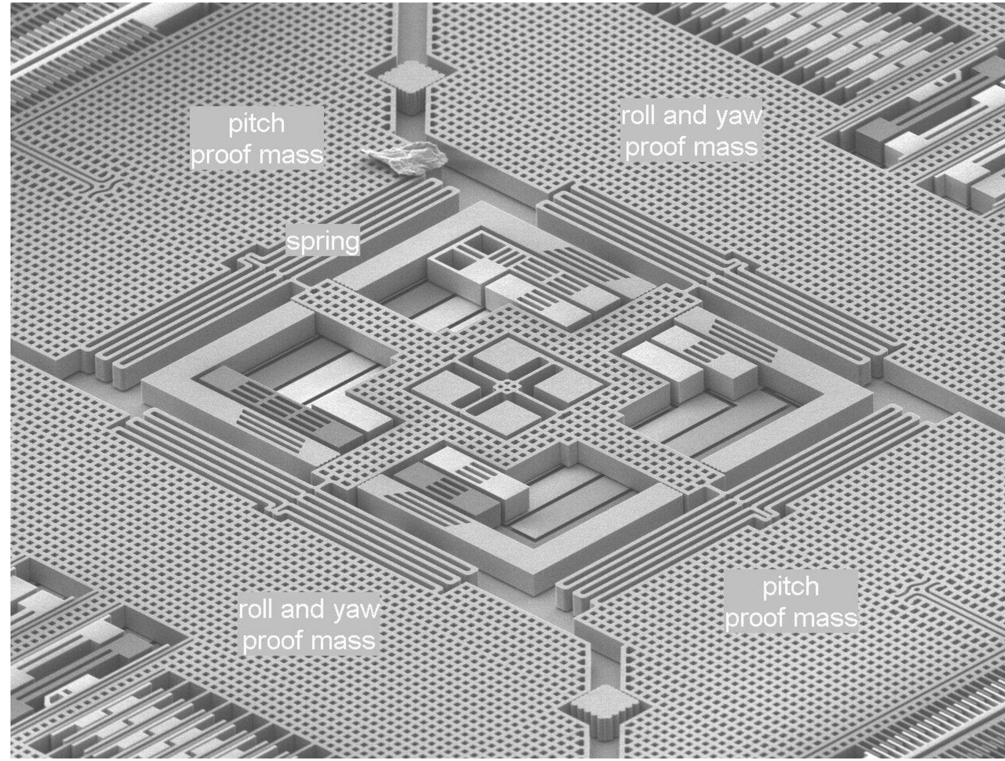
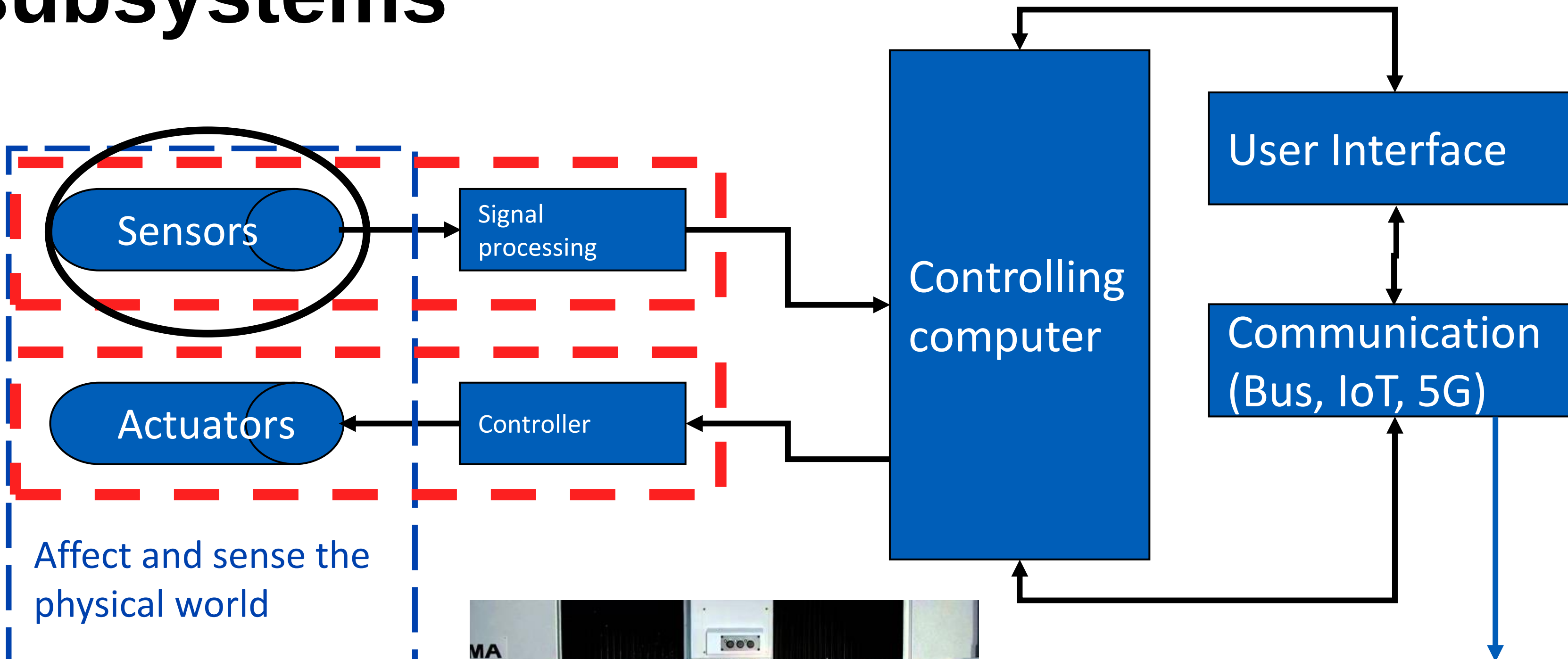
Aalto University
School of Engineering

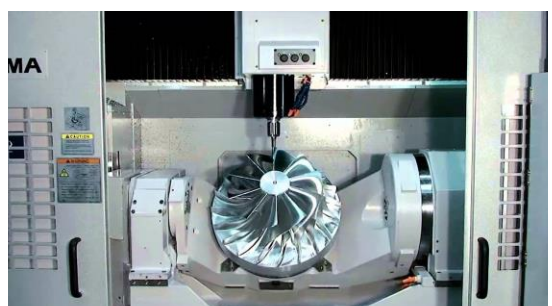
Sensors 2



KON-C2004 Mechatronics Basics
Raine Viitala 13.11.2024

Mechatronic machine - subsystems





Lecture topics & learning outcomes

Strain based sensors – force, torque, pressure

Magnetic sensors

Temperature sensors

Inertial sensors

Microelectromechanical systems

Sensor fusion etc.

-> Know the operating principle of multiple ”other sensor” types

Force & torque

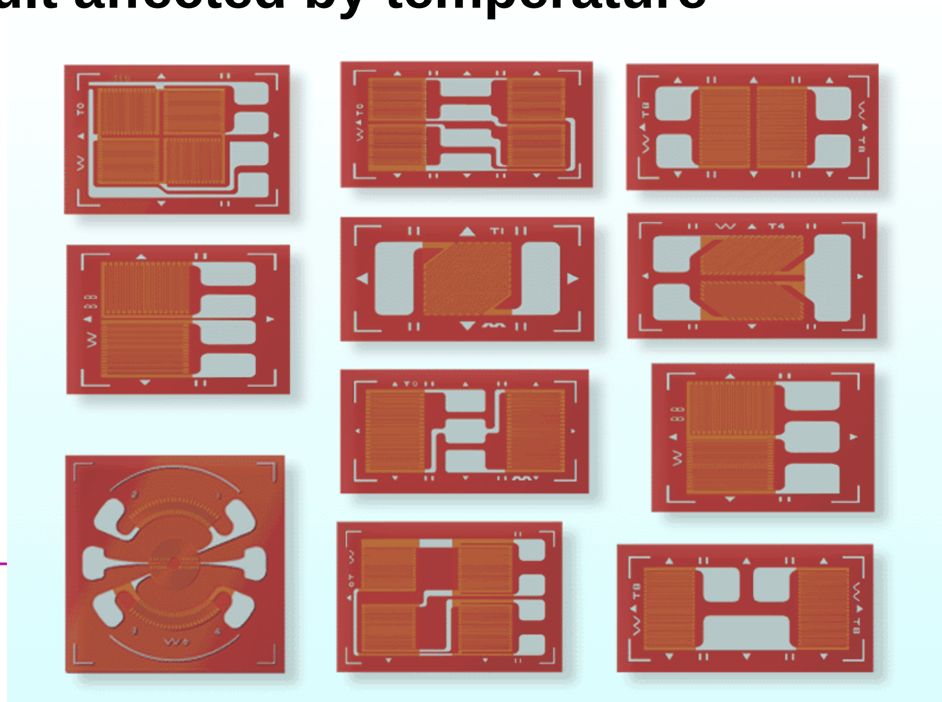
Strain gauge

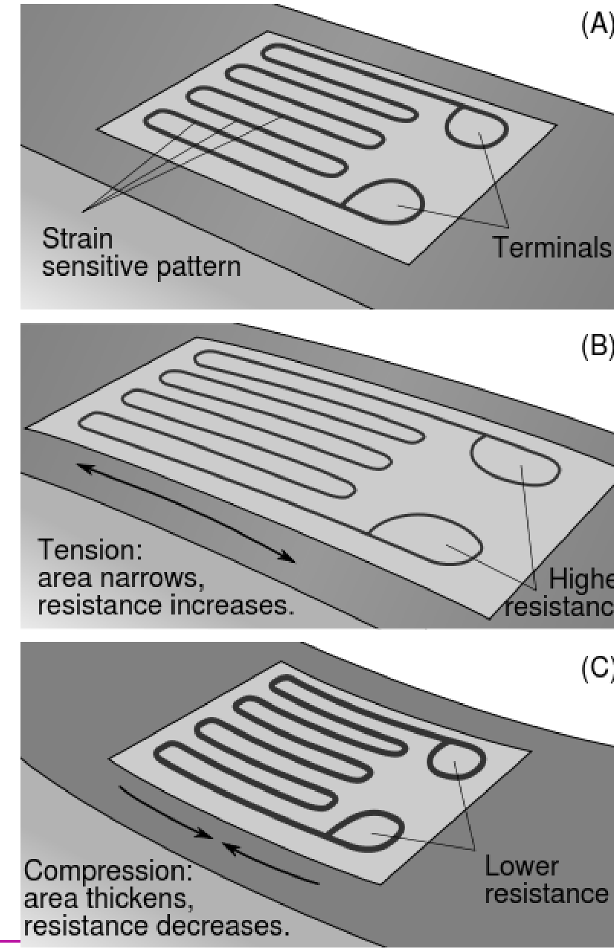
http://en.wikipedia.org/wiki/Strain_gauge

Resistance changes when the gauge deforms

$$R = \rho \frac{l}{A}$$

Result affected by temperature

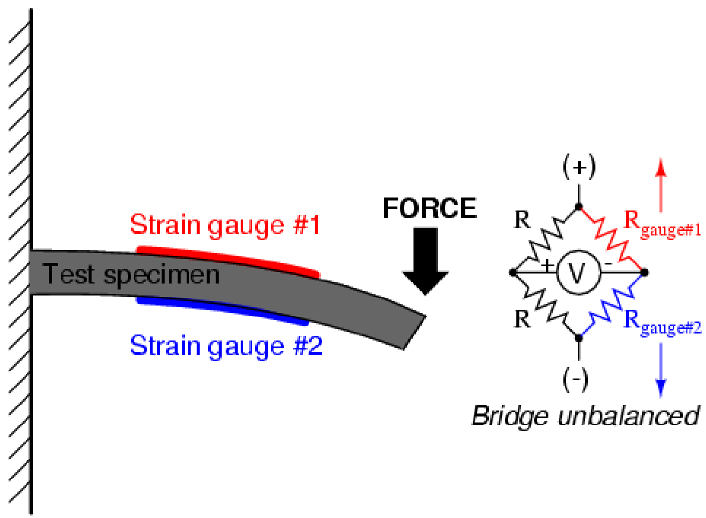




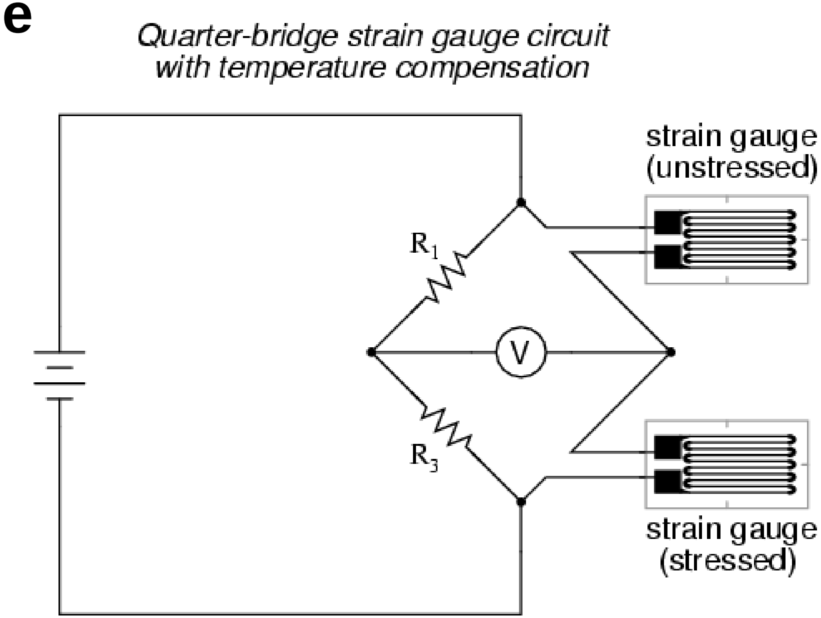
Wheatstone bridge for strain gauges

Zero centered, more sensitive output

Temperature compensating possible



http://www.allaboutcircuits.com/vol_1/chpt_9/7.html



http://www.allaboutcircuits.com/vol_1/chpt_9/7.html

Piezoelectricity

Piezo ~ "pressure," from Greek "to press tight, squeeze,"

Mechanical strain generates electric charge in material

- *Or charge generates strain*

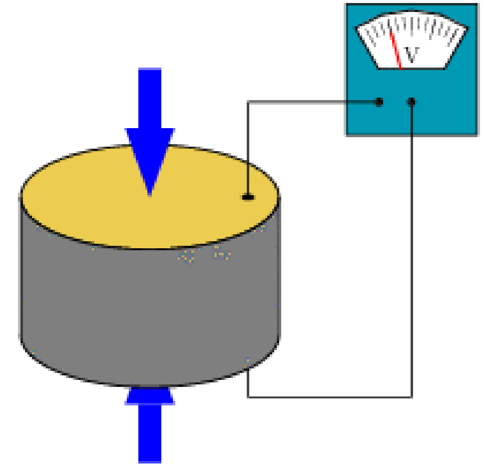
Very high dynamics

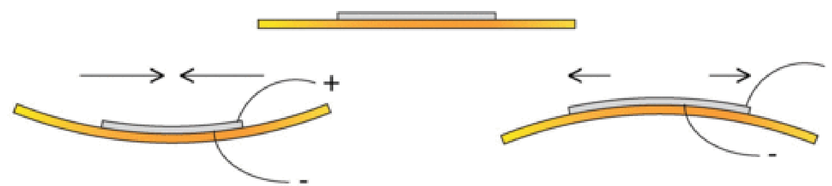
Sensors and actuators

Oscillators

- *Quartz clock*
- *Microprocessors*

http://en.wikipedia.org/wiki/Piezoelectricity



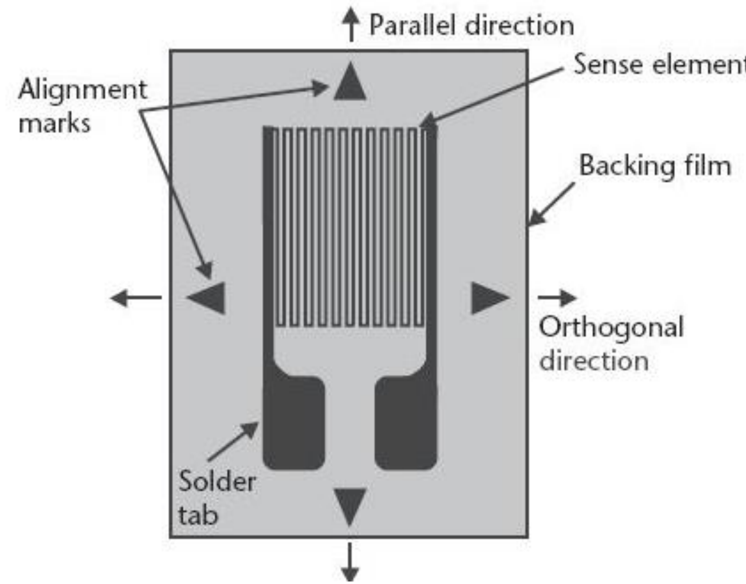


http://upload.wikimedia.org/wikipedia/commons/thumb/3/3a/PiezoBendingPrinciple.gif/640px-PiezoBendingPrinciple.gif

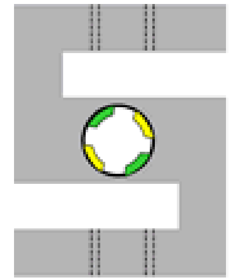
Piezoresistivity

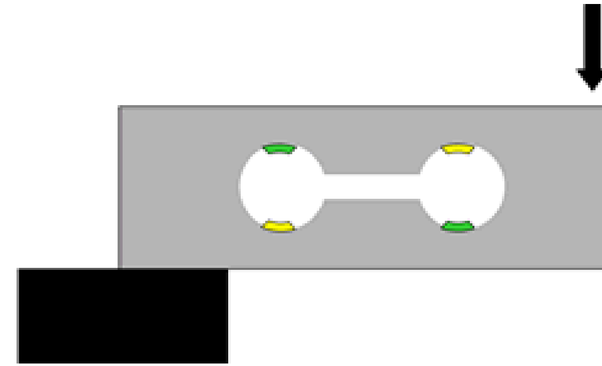
Mechanical strain induces a change in semiconductor’s electrical resistivity

- *Highly temperature sensitive*
  - Can be compensated for
- *Larger change than in normal strain gages*
  - More sensitive sensors



Force sensors (load cell)





Strain gauge

- *Measures deformation*
- *Stable, linear*

Piezoelectric load cells

- *High dynamics, very sensitive*
- *Small size*
- *Charge leaks -> measurement drifts*
    - No static measurements

http://www.appmeas.co.uk/load-cells-and-force-sensors.html

Torque sensors

Often strain gage based

Also encoder based measurement of axle torsion

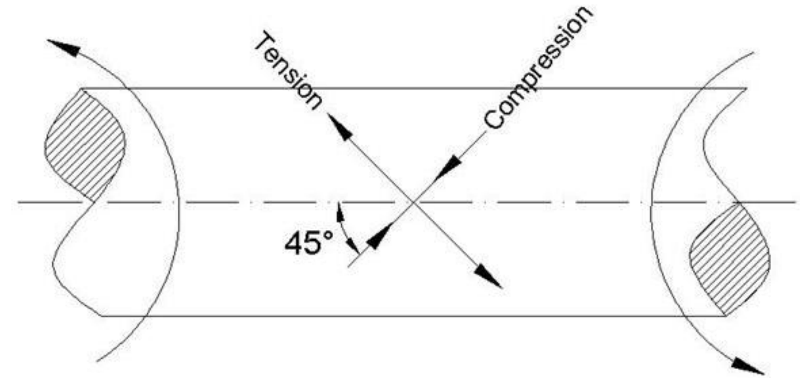
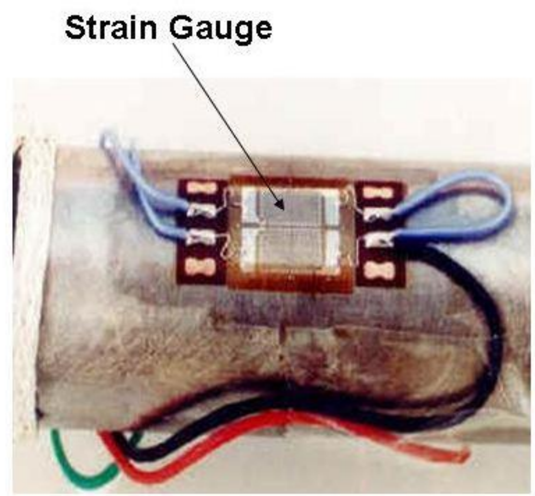


Figure Showing the Stress Developed in a Shaft Under Torsion



http://www.brighthubengineering.com/machine-design/65871-how-to-measure-torque-requirements-for-gear-box/

Pressure sensors

Piezoresistive

- *Most common*

Piezoelectric

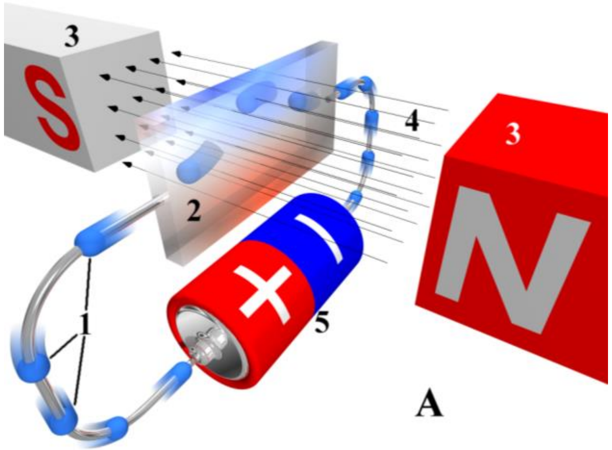
- *High dynamics. Drifting due to leakage.*

Strain gauge

Capacitive

Hall effect

Hall effect



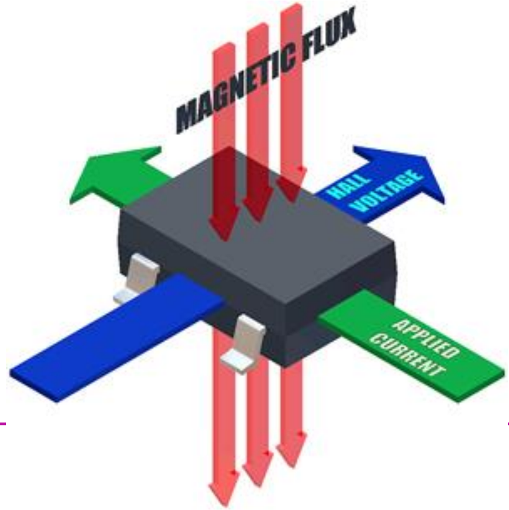
External magnetic field causes a voltage in the sensor

- *Current sensors*
- *Magnetic field sensors*

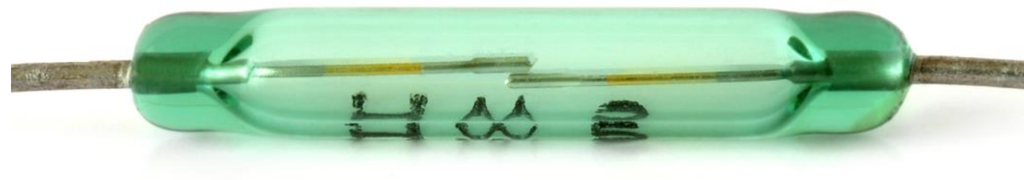
Very high dynamics

Robust sensors since no contact

- *Integrated into one chip*

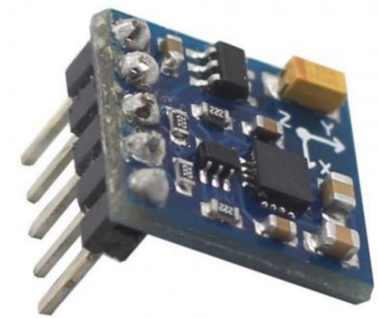


Magnetic sensors



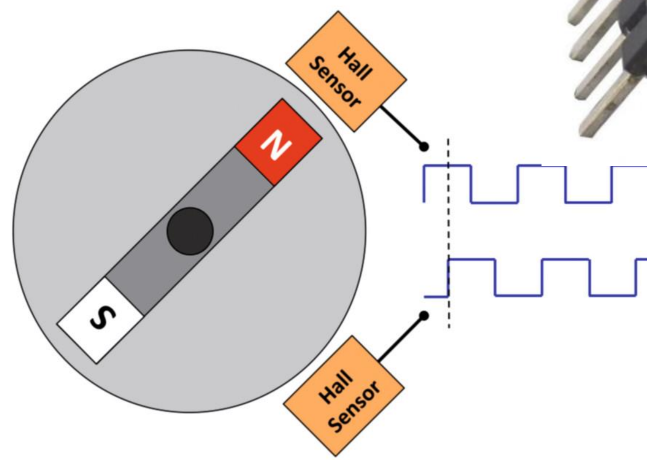
Magnetic switch

- *Mechanical or electrical*
- *Magnetic field intensity*
- *On/off*
  - Motor commutation



Magnetometer

- *Senses magnitude and direction of external magnetic field*
- *Electric compass*

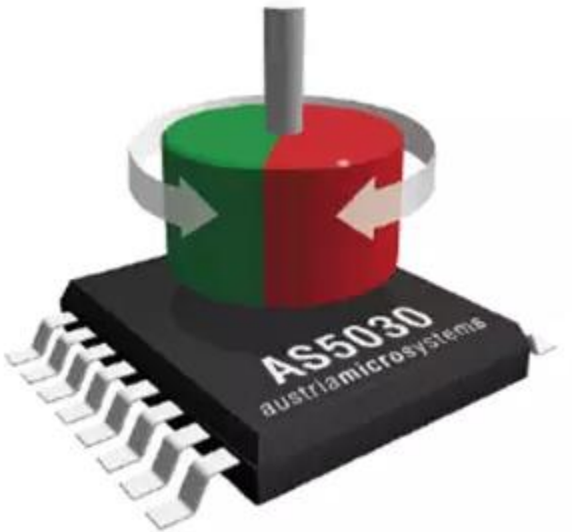


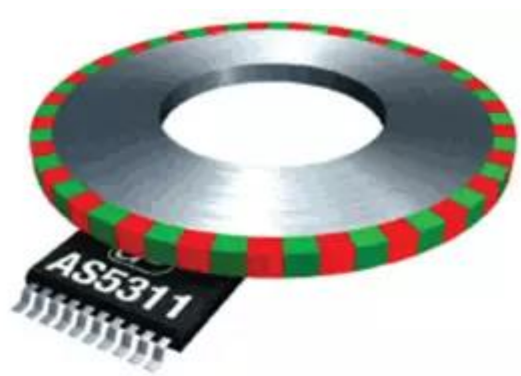
A reed kapcsoló működése

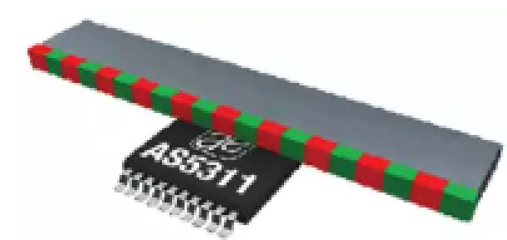
Operation of the reed switch

Magnetic encoders

- **Hall sensors sense the direction or the change of the magnetic field**
  - E.g. gear tooth recognition

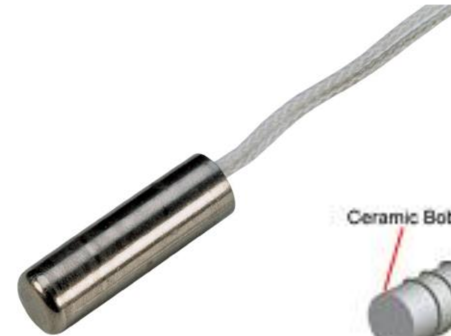


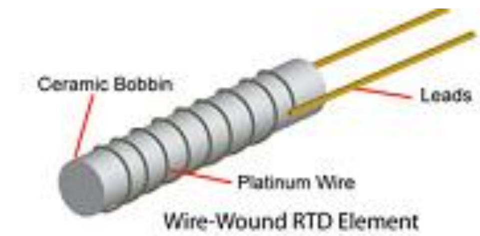


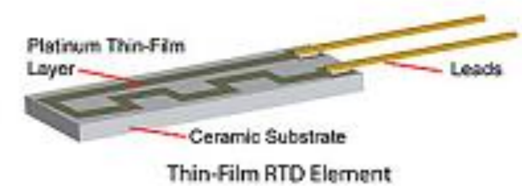


Temperature & imaging

Temperature







http://sensorwiki.org/doku.php/sensors/temperature

Thermocouple

- *Change in voltage, a few µV per °C*
- *Temperature up to 2000 °C, fast response*

Resistance temperature sensor/detector (RTD)

- *Change in resistance (Pt100 100 ohm at 0 °C)*
- *High accuracy, linear response*
- *Usually for temperatures below 600 °C*

Thermistor (NTC/PTC) (negative/positive temperature coefficient)

- *Semiconductor*
- *Resistance changes. Exponential response -> limited range*
- *Temperature up to 1700 °C*

Pyroelectricity

Change in temperature (infrared radiation) causes voltage difference in certain materials

Application: Passive Infrared (PIR) motion sensors

https://en.wikipedia.org/wiki/Passive_infrared_sensor#/media/File:Motion_detector.jpg

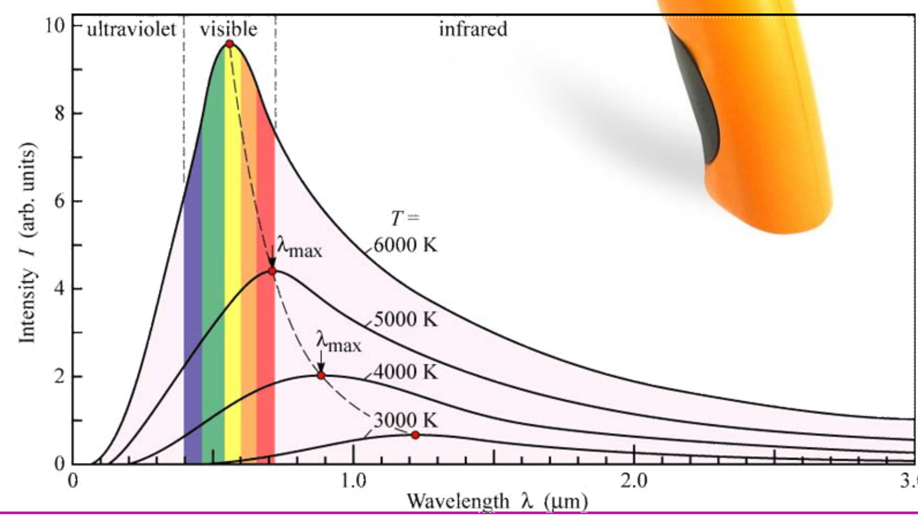
Contactless temperature measurement

All objects emit black body radiation

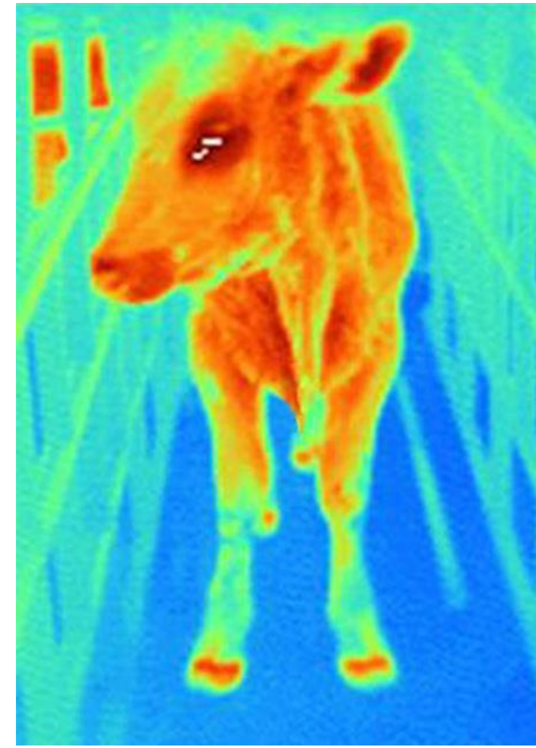
- **infrared ~ heat**

Benefits from contactless sensing

- *Moving objects*
- *Short response time*
- *Temperatures over 1300° C*

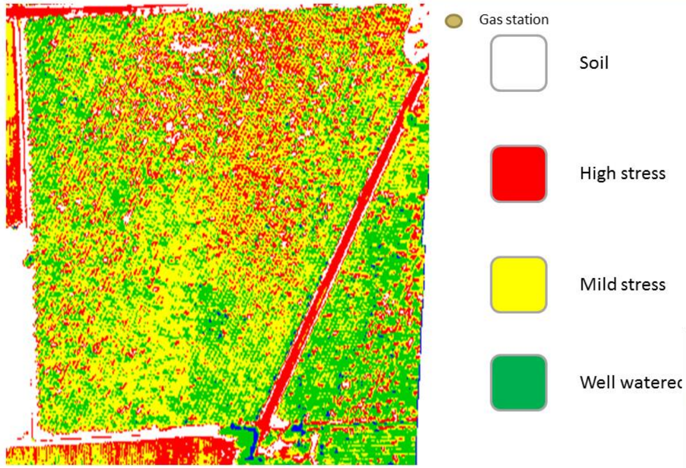


Thermal imaging

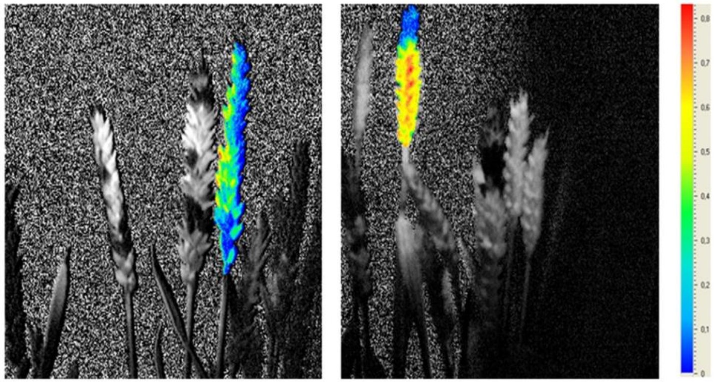


Hyperspectral imaging

Water stress map of 160 acre walnut orchard



https://hbr.org/2014/02/what-drones-and-crop-dusters-can-teach-about-minimum-viable-product

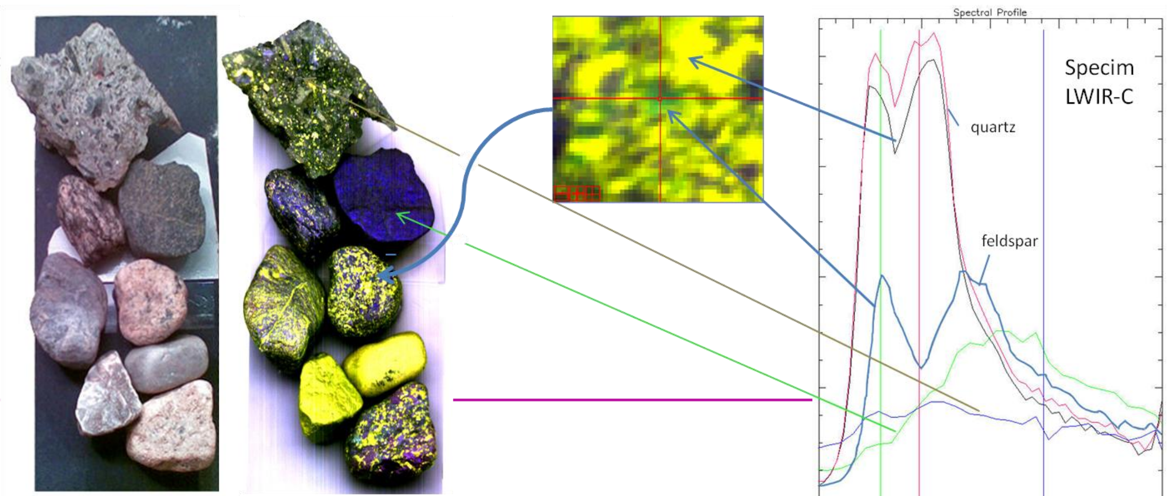


degree of infection: 90%

degree of infection: 30%

F_V/F_M false colour scale

https://en.wikipedia.org/wiki/Hyperspectral_imaging



RGB image

LWIR image

Lecture task

Form groups of 2-4.

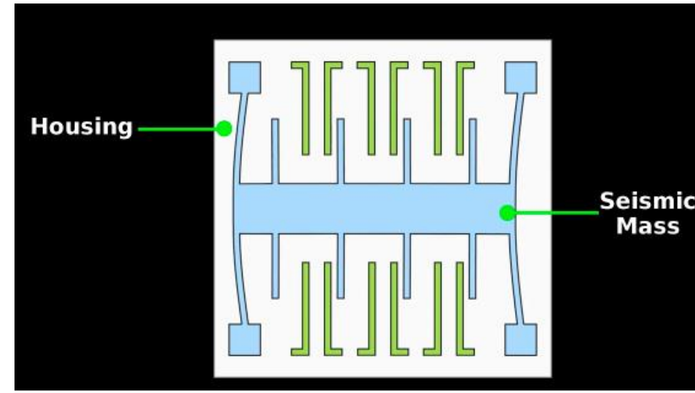
What applications can you find for hyperspectral imaging on the internet?

Prepare to introduce one in small groups

Inertial

Acceleration sensors

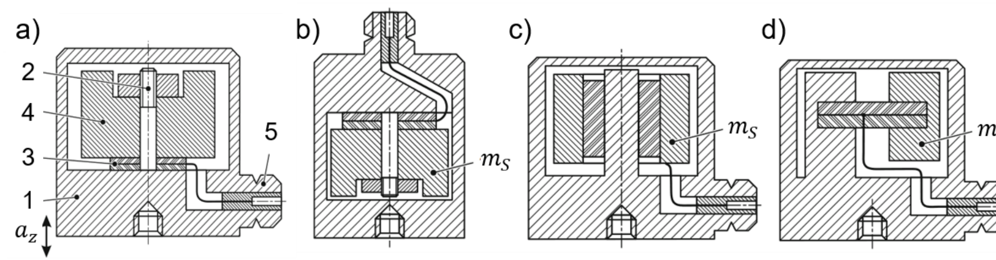
http://en.wikipedia.org/wiki/Piezoelectric_accelerometer



Navigation, inclination, vibration, input devices, screen orientation

Based on

- *Piezoelectricity*
- *Piezoresistivity*
- *Capacitive sensing*



1 housing, 2 preloading bolt, 3 piezoelectric elements, 4 seismic mass, and 5 electric connector.

http://www.leancrew.com/all-this/2012/05/accelerometers/

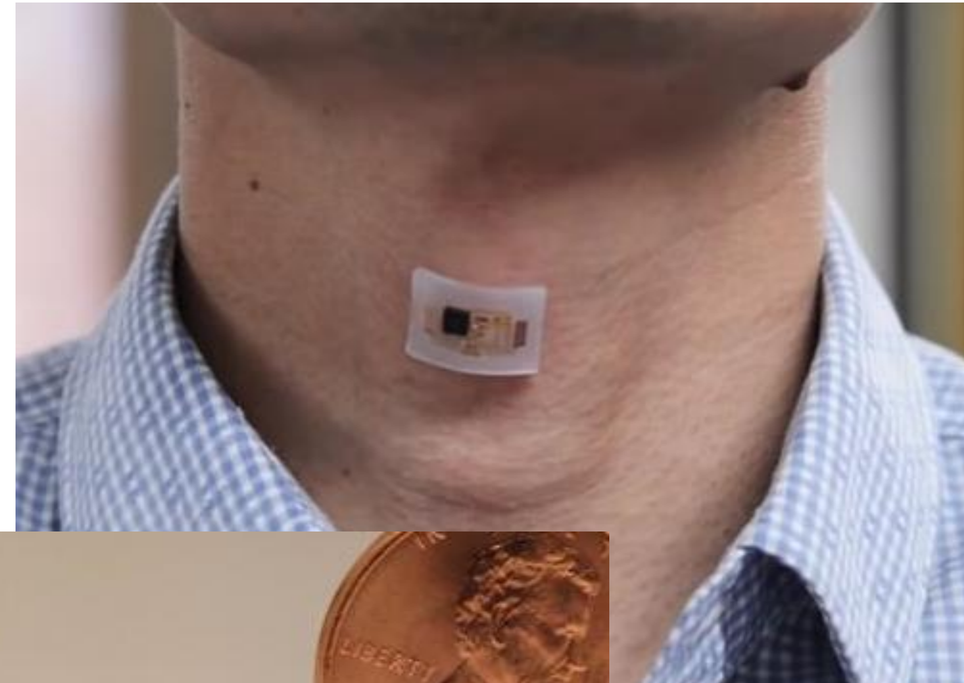
Example: wearable sensor

Accelerometer measures body vibrations

- *Heart rate*
- *Voice*

Lots of signal filtering

- *FFT etc.*



http://newatlas.com/heart-acoustic-sensor-monitor/46506/

Gyroscope

http://www.sensorwiki.org/doku.php/sensors/gyroscope

Measures rate of angular rotation

- *Bias stability (drift), angle random walk, maximum rate of change*

Navigation, platform stabilization

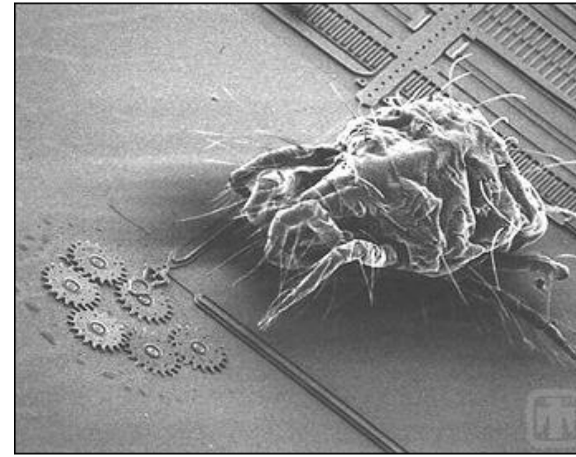
Principles

- *Mechanical – complex, expensive, very accurate*
- ***MEMS – low cost & power**, often not very accurate (drift >10 deg/h)*
- *Optical – accurate, medium cost, shock tolerant*

MEMS sensors

https://www.maximintegrated.com/en/app-notes/index.mvp/id/5418

MEMS



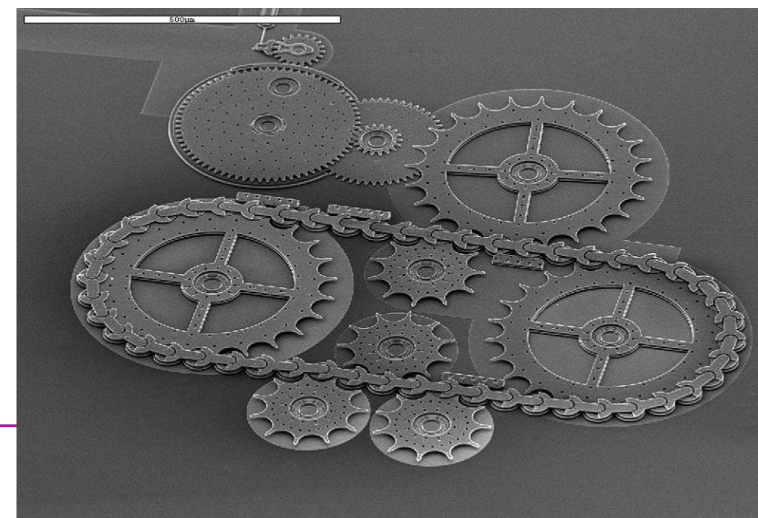
Microelectromechanical system

- *Part dimensions 1-100 µm*

Low power

Produced like electronic circuits

- *Mass manufacturing -> cheap*



http://rmmechanical.blogspot.fi/2010/11/micro-electro-mechanical-systems-mems.html

Photolithography

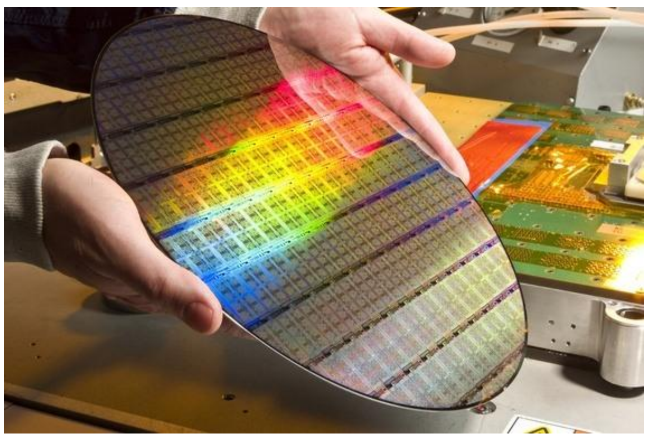
Deposit

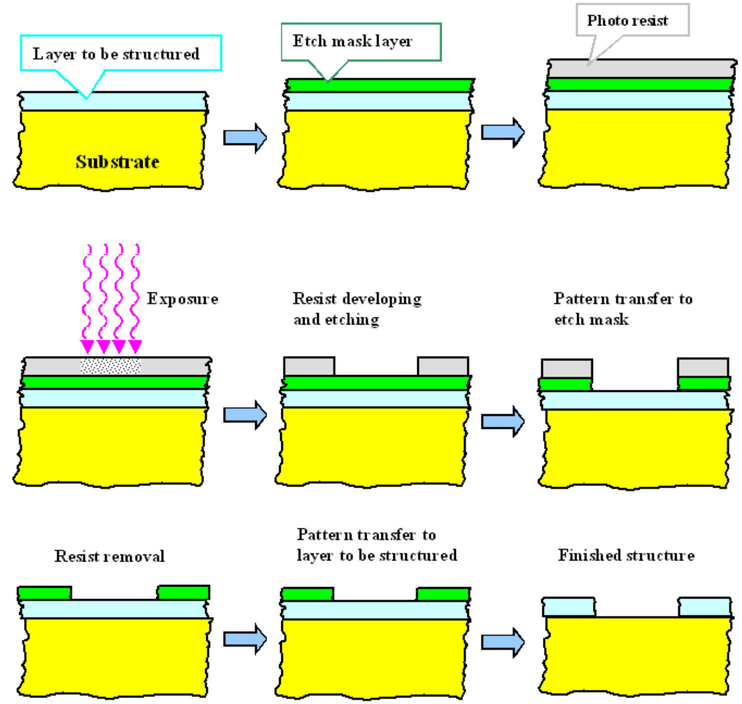
Mask

Etch

Repeat

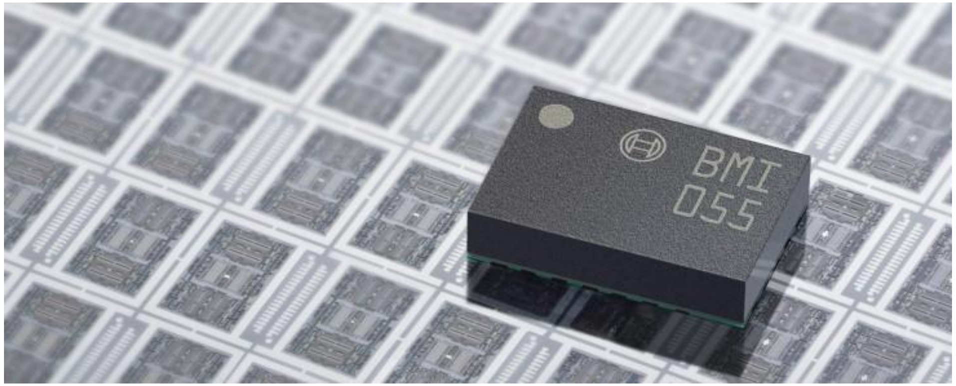
Dutch company ASML dominates





MEMS gyroscopes

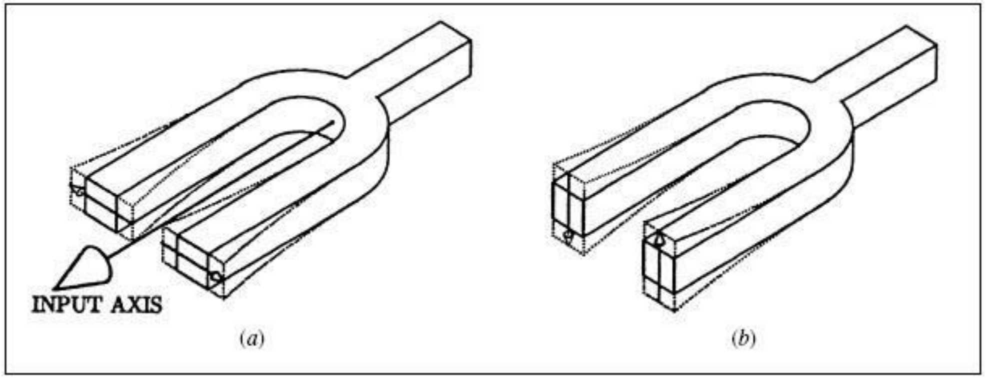
http://www.bosch-sensortec.com/de/homepage/products_3/6_axis_sensors_2/inertial_measurement_unit_1/inertial_measurement_unit_2



Cheap, small, low power

Error sources

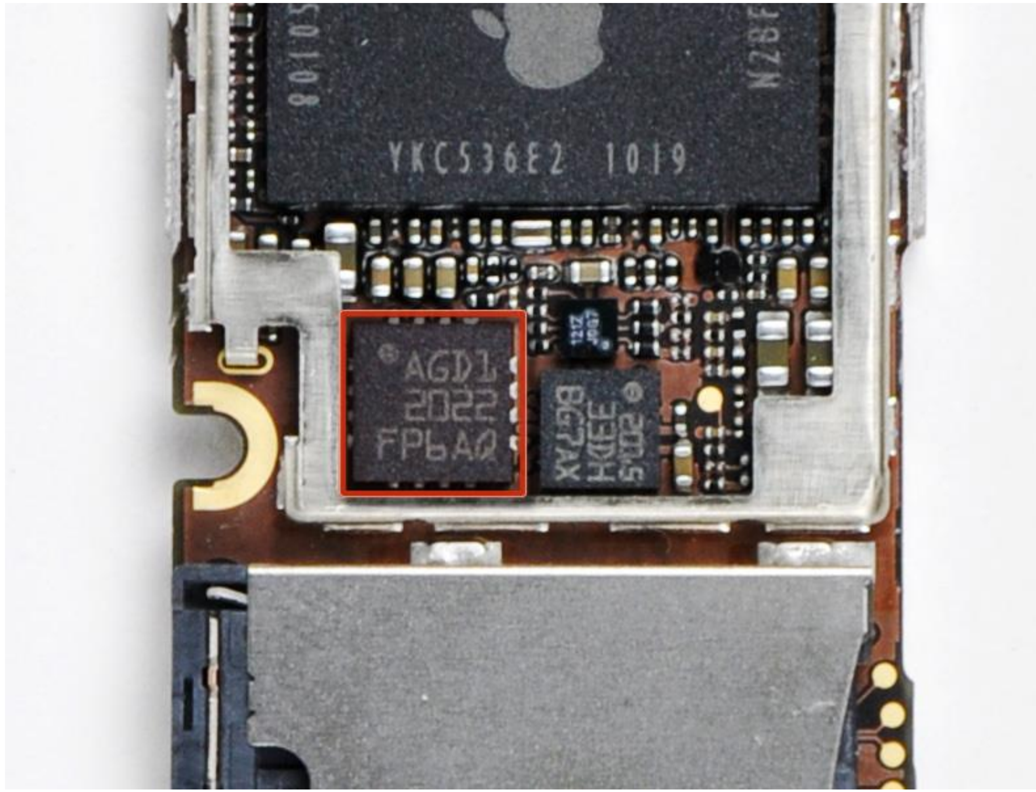
- *Bias error causes drift 1-1000° /h*
- *Acceleration (**vibration**)*
  - Tilting causes acceleration
- *Shocks*
- *Exceeding range*



http://www.memsjournal.com/2011/01/motion-sensing-in-the-iphone-4-mems-gyroscope.html

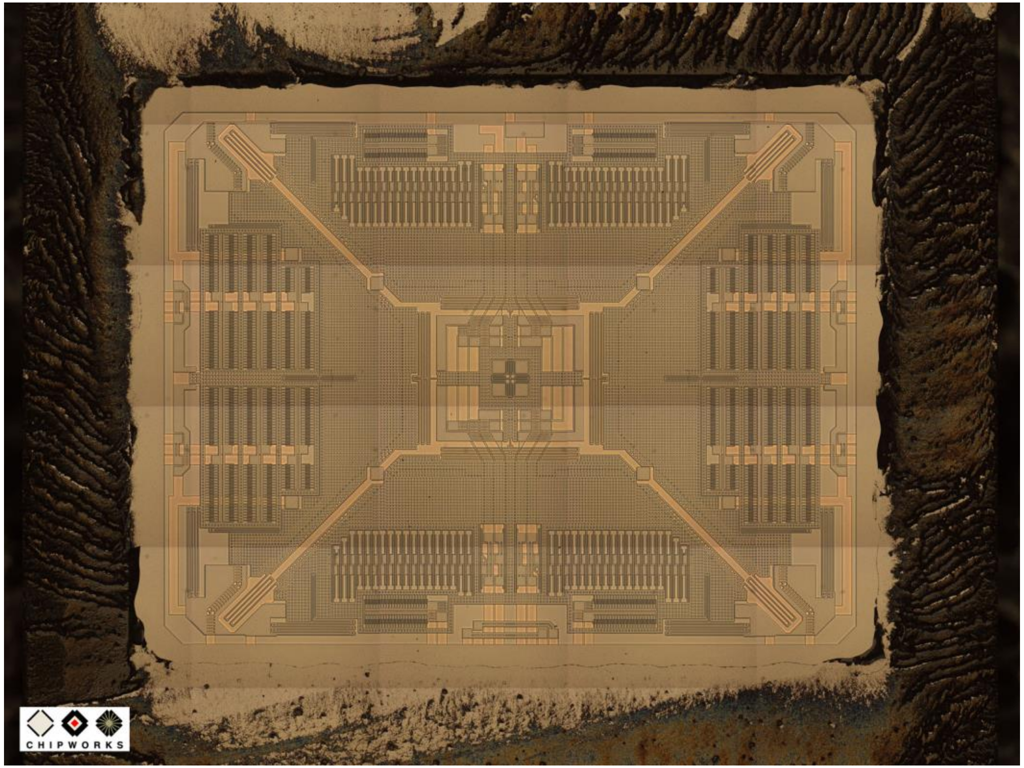
MEMS acceleration sensor

MEMS example: Iphone 4 gyroscope

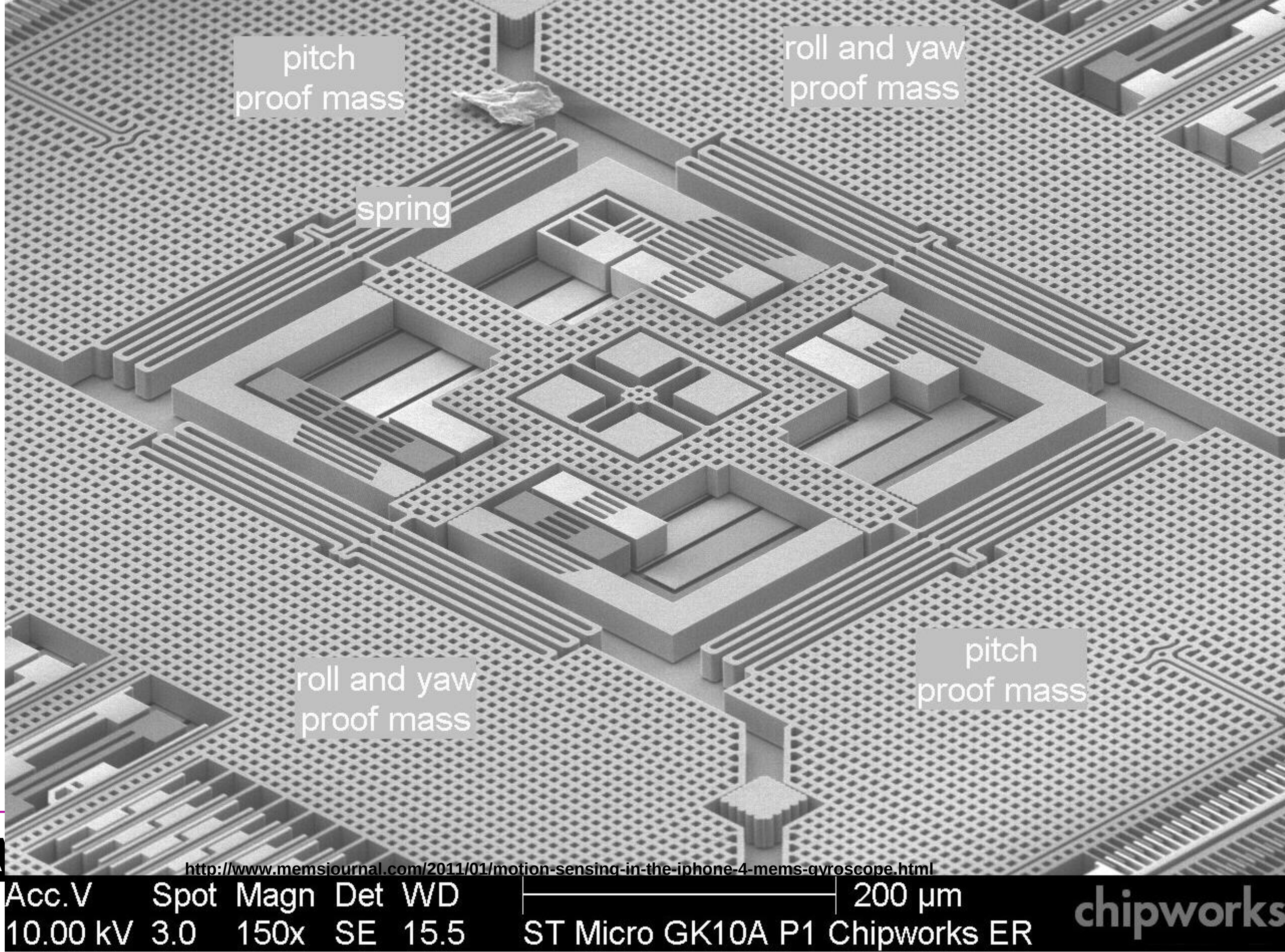


https://www.ifixit.com/Teardown/iPhone+4+Gyroscope+Teardown/3156

MEMS example: Iphone 4 gyroscope



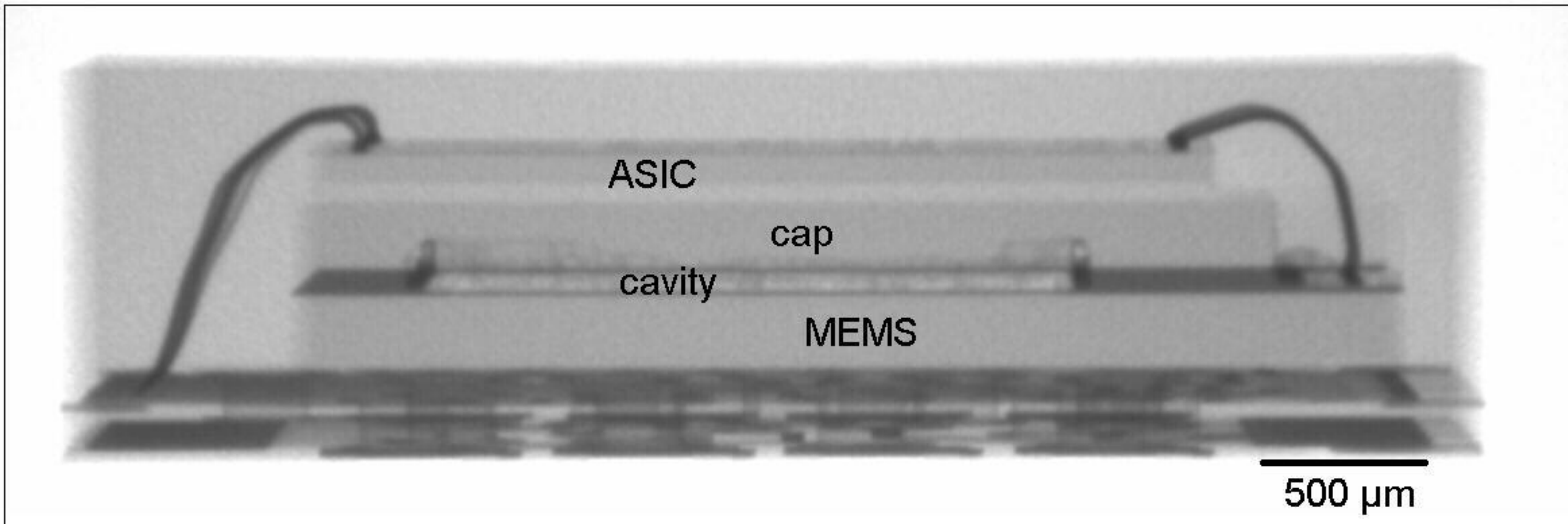
https://www.ifixit.com/Teardown/iPhone+4+Gyroscope+Teardown/3156



http://www.memsjournal.com/2011/01/motion-sensing-in-the-iphone-4-mems-gyroscope.html

A

MEMS example: Iphone 4 gyroscope



http://www.memsjournal.com/2011/01/motion-sensing-in-the-iphone-4-mems-gyroscope.html

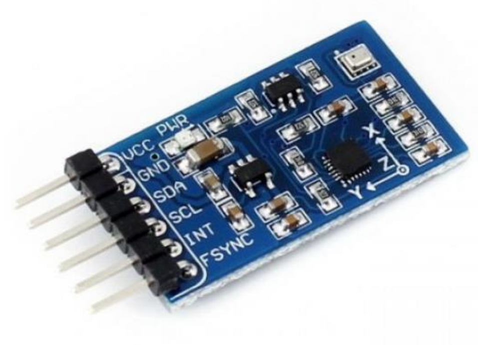
Sensor fusion

Inertial measurement unit (IMU)

2-11 degrees of freedom (DOF)

- *1-3 axis accelerometer*
- *1-3 axis gyroscope*
- *1-3 axis magnetometer*
- *"Extra" sensors*
  - Pressure (altitude from atmospheric pressure)
  - GPS

Sensor fusion



Sensor fusion

Combine several sensors to increase precision

Table 1: Summary Sensor Advantages and Issues

Sensor Type	Advantages	Issues
Accelerometer	• Fast. • Absolute for "down".	• Cannot measure heading/yaw. • Accumulated error due to jitter and noise, etc.
Gyroscope	• Fast. • Measures relative orientation on all 3 axes.	• No absolute references. • Long-term bias change, which leads to heading drift.
Geomagnetic Sensor	• Absolute for "heading".	• Magnetic anomaly distorts heading.

http://www.edn.com/design/sensors/4402401/2/Motion-sensors-de-mystified

Kalman filter

Algorithm to get ”optimal” results from several sensors

Left: Accelerometer, Middle: Kalman fusion, Right: Gyroscope

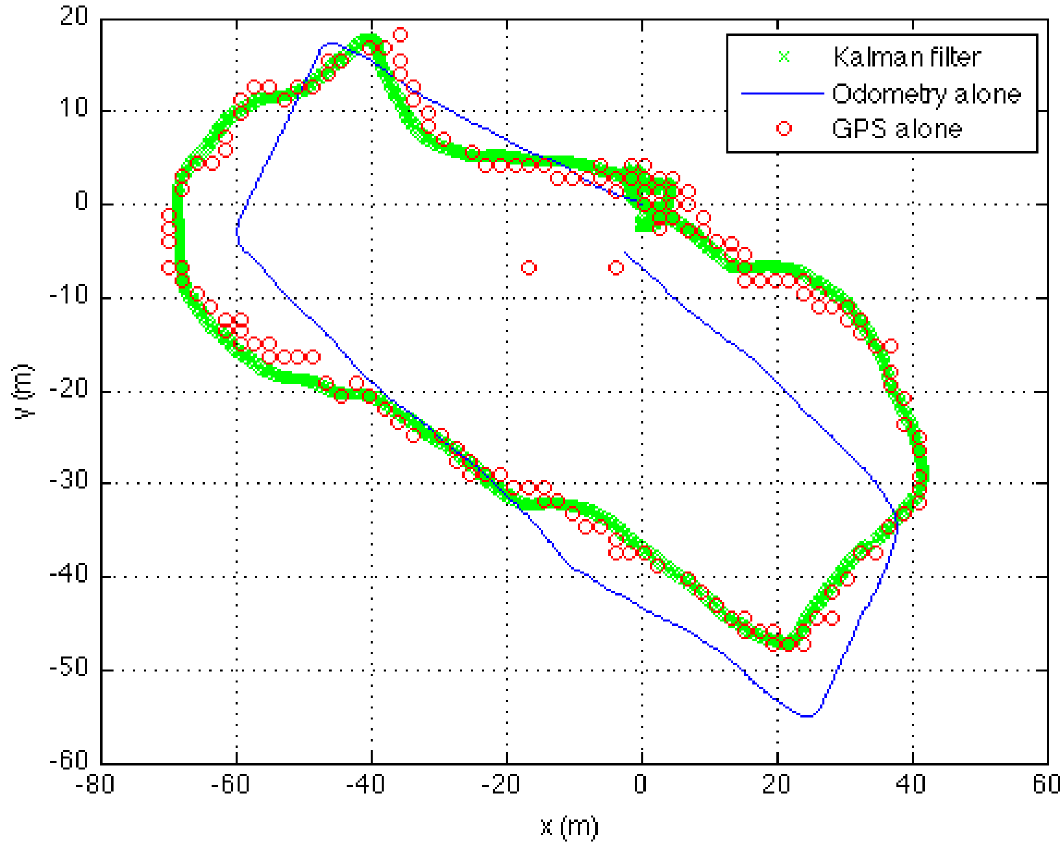
Sensor fusion for positioning

Absolute measurement (GPS)

vs.

incremental (odometry)

Odometry= data from position sensors such as encoders in wheels and steering wheel



Summary

Everything that can be converted to voltage, current or charge can be measured

Absolute vs incremental sensors

MEMS sensors are cheap and getting more accurate

Sensor fusion

Misc.

Indirect measurements

Strain -> Pressure

Pressure ->Hydraulic force

Force -> Mass

Acceleration -> Position/velocity

Pressure -> Fluid velocity

Back emf voltage -> Motor speed

Other sensors

Electrical – voltage, current

Light – intensity, spectrum

Material concentration – pH, gas detectors etc.

Flow – air or liquid

Radiation – geiger counter

Acoustic

Other sensors – civil engineering

Humidity

Temperature

Light intensity

Carbon dioxide

Air speed

Radiation

Smoke detector