CENG 4480
Lecture 04: Sensors

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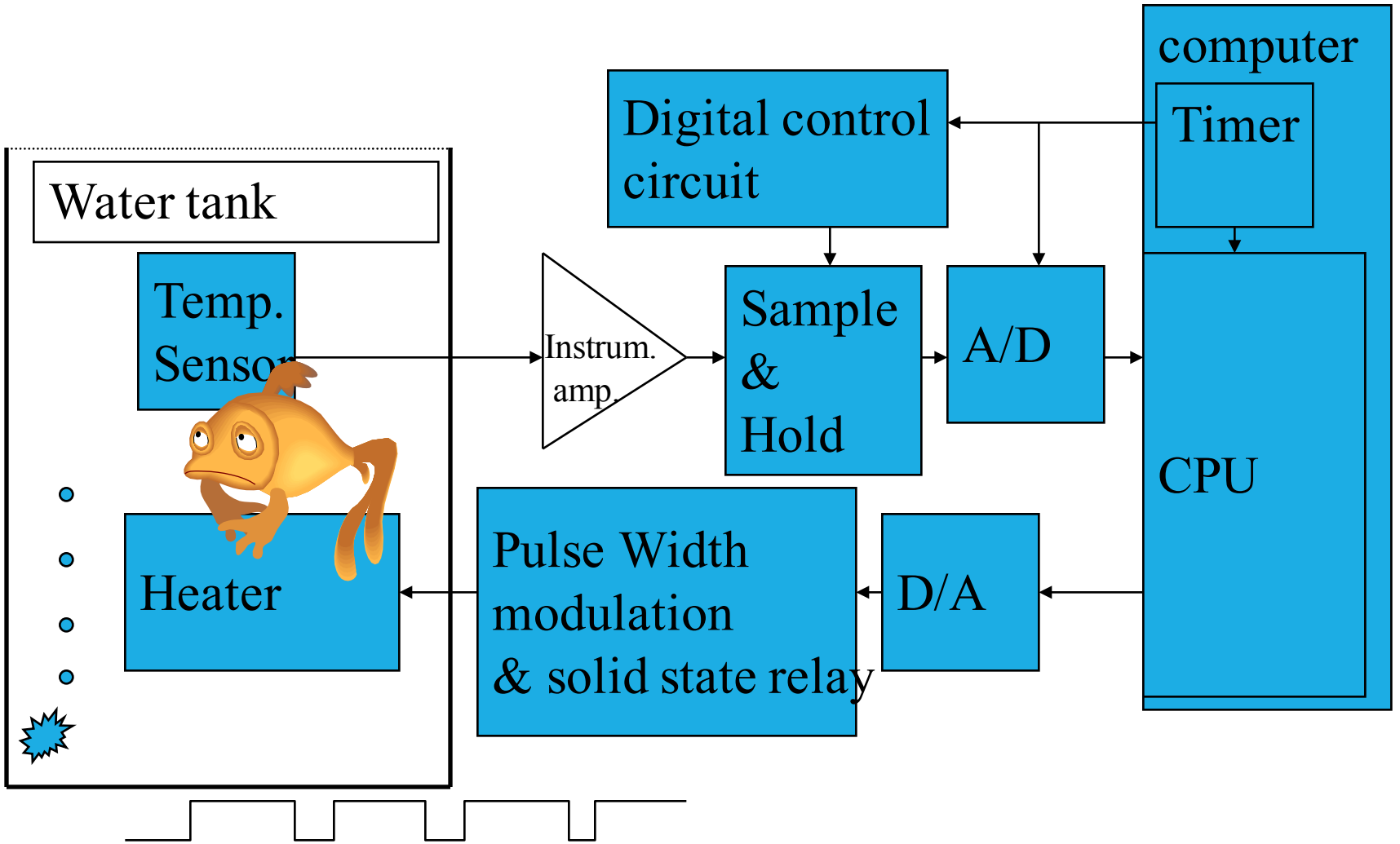
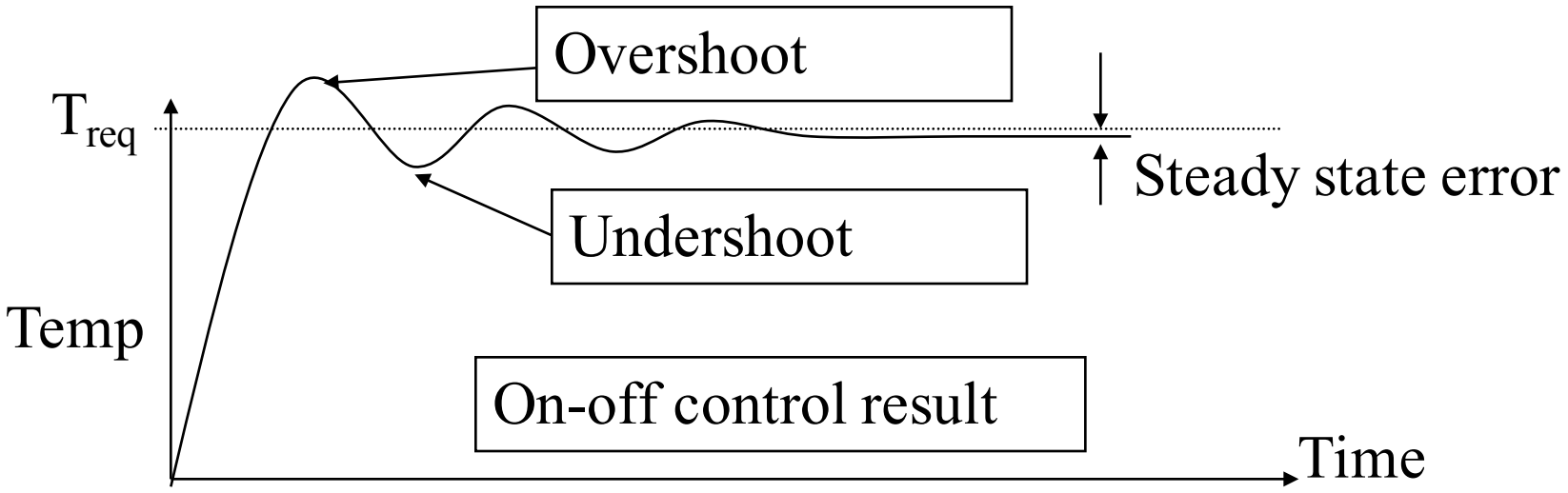
Control systems
Example: A temperature control system

Control example: Temperature control system



Temperature control method 1: ON-Off (bang-bang) control (poor)

- Easy to implement, bad control result -- contains overshoot undershot. Algorithm for on-off-control:
- Loop forever: If ($T_{from\_sensor} > T_{req}$ required temperature)
- then (heater off)
- else (heater on).



Sensors

- Motion (Orientation/inclination) sensors
- Force/pressure/strain
- Position
- Temperature and humidity
- Rotary position
- Light and magnetic field sensors

Motion (Orientation/inclination) sensors

- Acceleration
- Gyroscope
- Compass
- Tilt Sensor

Accelerometer

- Electromechanical devices that sense
  - Static acceleration (gravity)
  - Dynamic acceleration (vibrations & movement)

- Functions:
  - measure acceleration in one or more directions, position can be deduced by integration.
  - Orientation sensing : tilt sensor
  - Vibration sensing
- Methods:
  - Mass spring method `ADXL78` (from Analog Device)
  - Air pocket method (`MX2125`)

ADXL78 (Mass spring method)

- http://www.analog.com/media/en/technical-documentation/data-sheets/ADXL78.pdf
- Measure the capacitance to create output
- Measure both dynamic & static acceleration

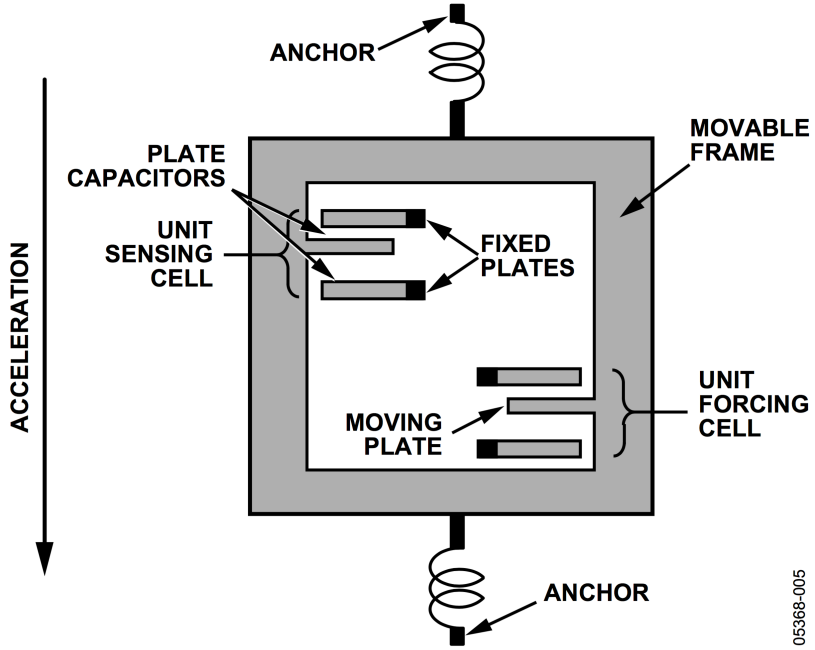


Figure 5. Simplified View of Sensor Under Acceleration

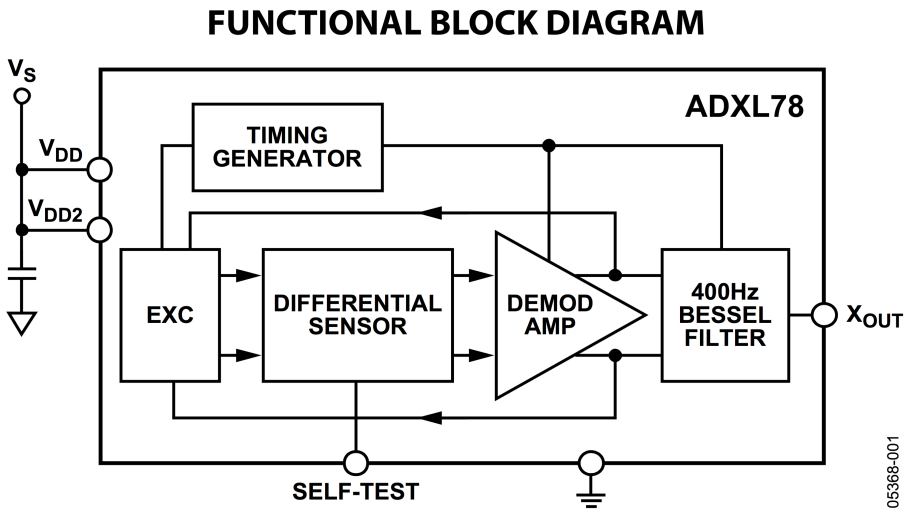


Figure 1.

ADXL330 Accelerometer for (X,Y,Z) Directions

- www.analog.com/media/en/technical-documentation/data-sheets/ADXL330.pdf
- 3D

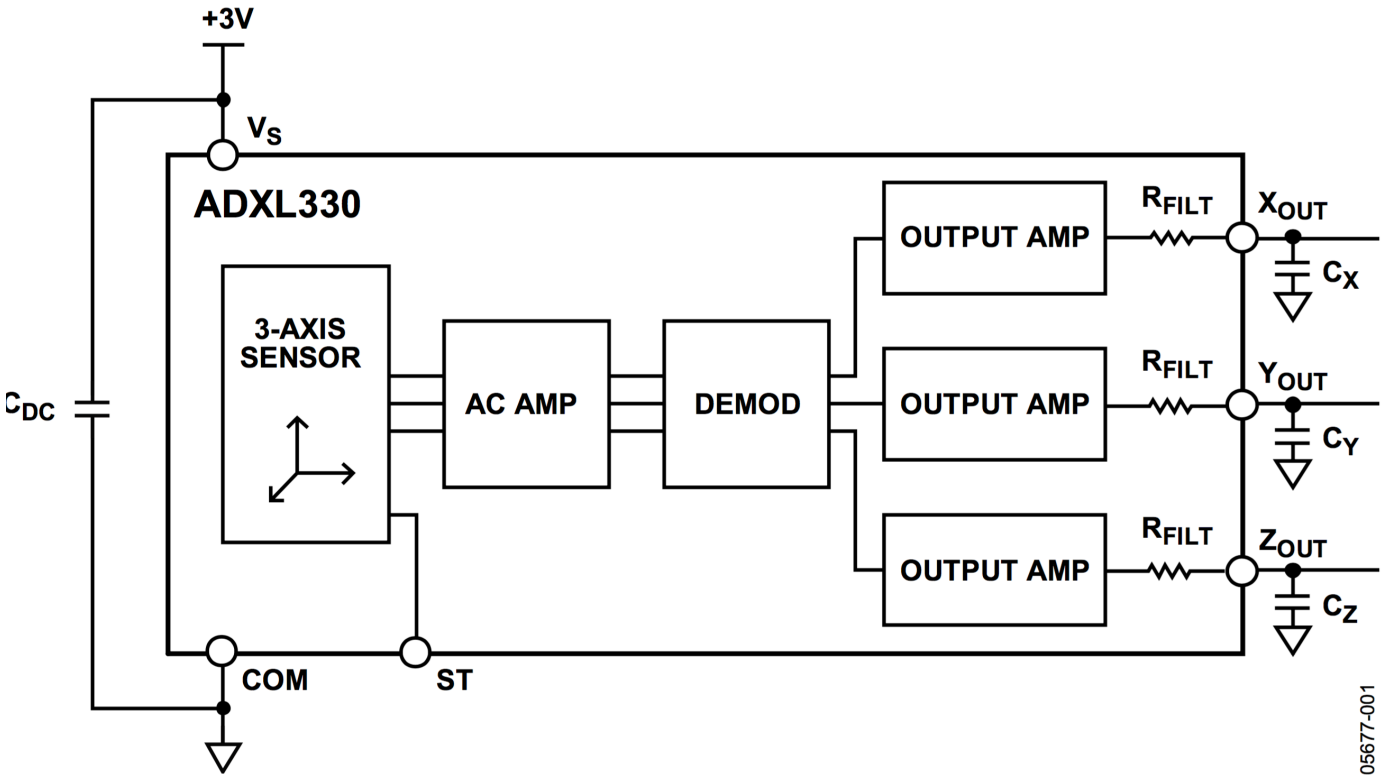


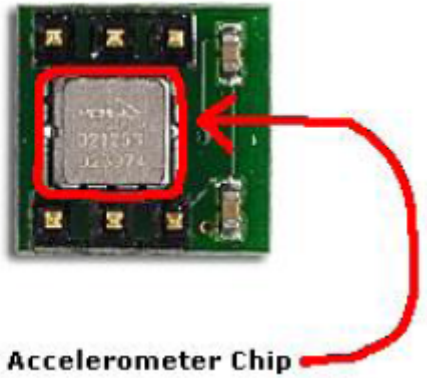
Figure 1.

2D Translational Accelerometer MX2125

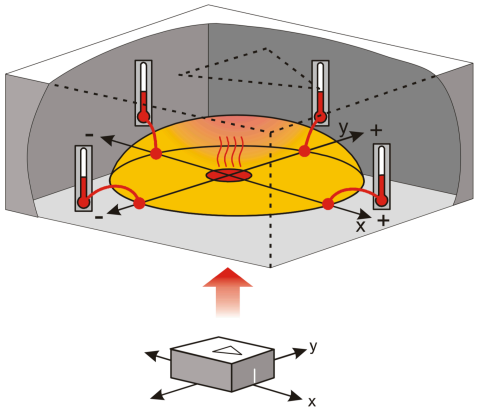
http://www.jameco.com/Jameco/Products/ProdDS/282870.pdf

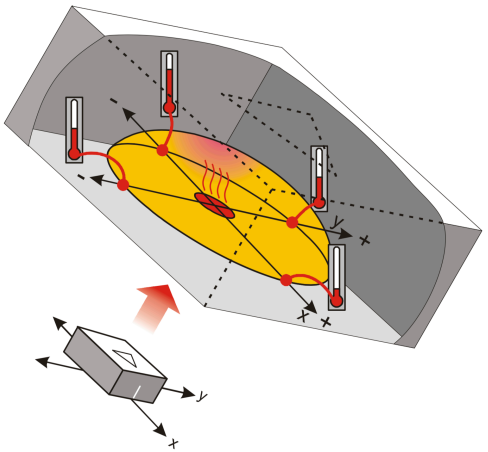
- Gas pocket type
- When the sensor moves, the temperatures of the 4 sensors are used to evaluate the 2D accelerations

Accelerometer Module

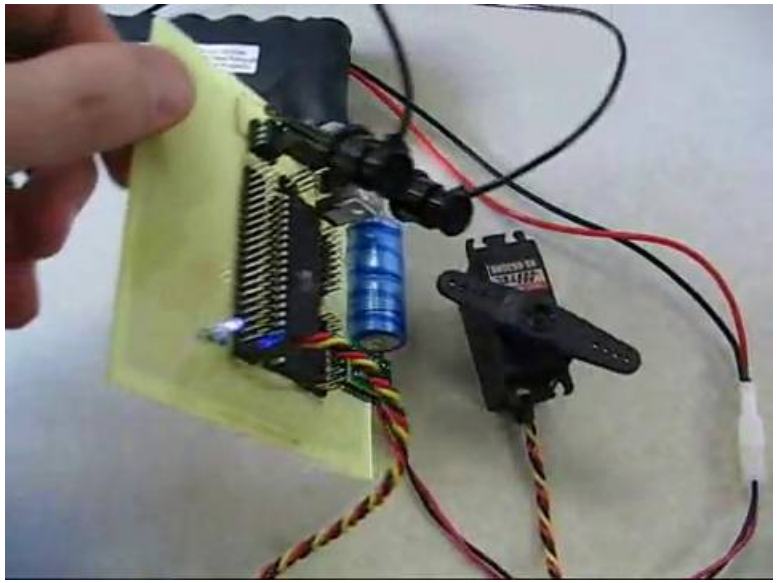


Accelerometer Chip





Demo: orientation sensing



Sensor demo

http://www.youtube.com/watch?v=9NEiBDBXFEQ

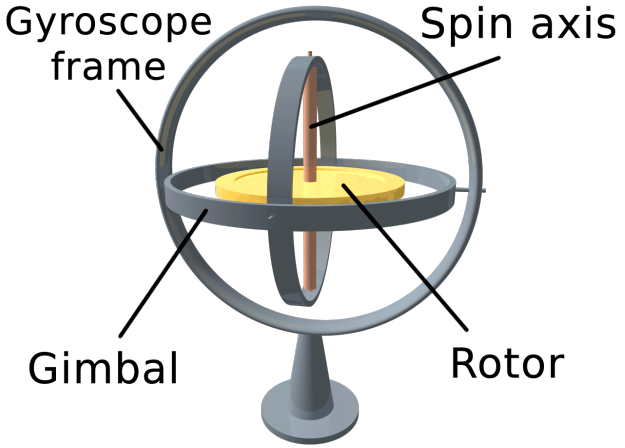
Demo: Tilt sensing demo

Tilt sensing demo
http://www.youtube.com/watch?v=C6uVrYz-j70

Gyroscopes

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

- Gyroscope
  - Measure rotational angle
- Rate Gyroscope
  - measure the rate of rotation along 3-axes of X (pitch), Y (roll), and Z (yaw).
  - Modern implementations are using Microelectromechanical systems (MEMS) technologies.



Gyroscope to Measure Rational acceleration

ADXRS401

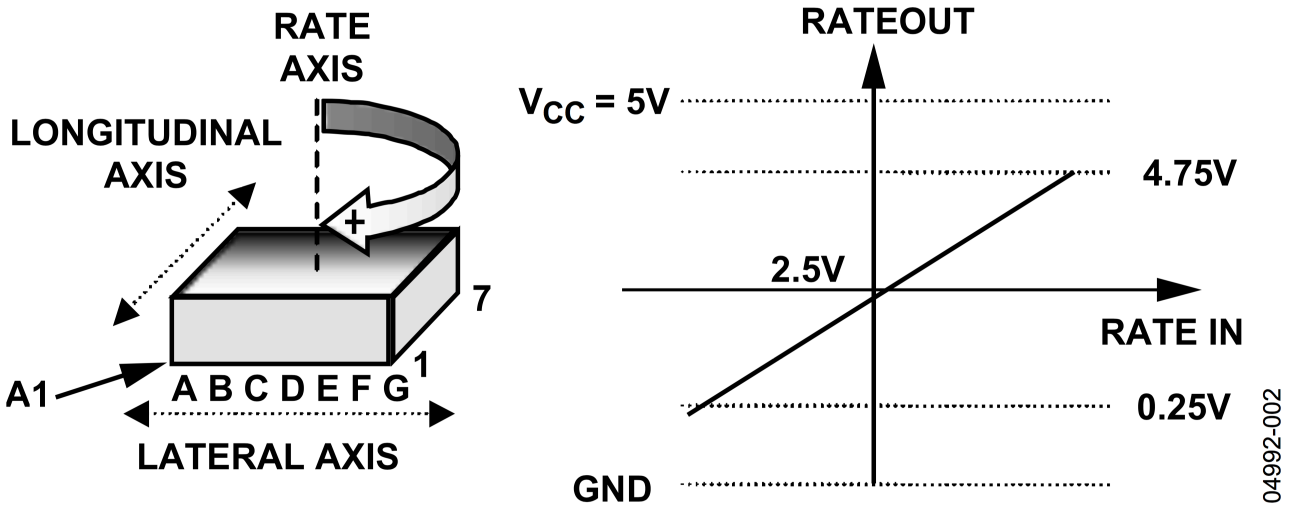
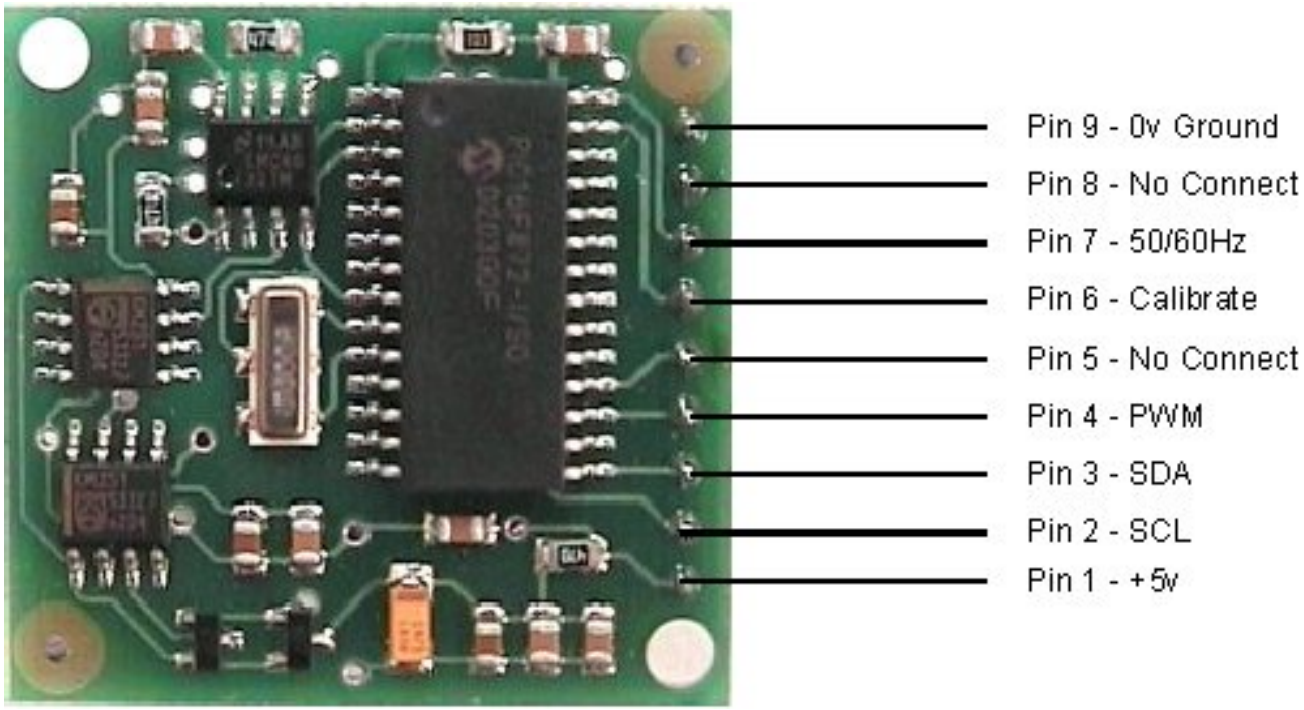


Figure 2. RATEOUT Signal Increases with Clockwise Rotation

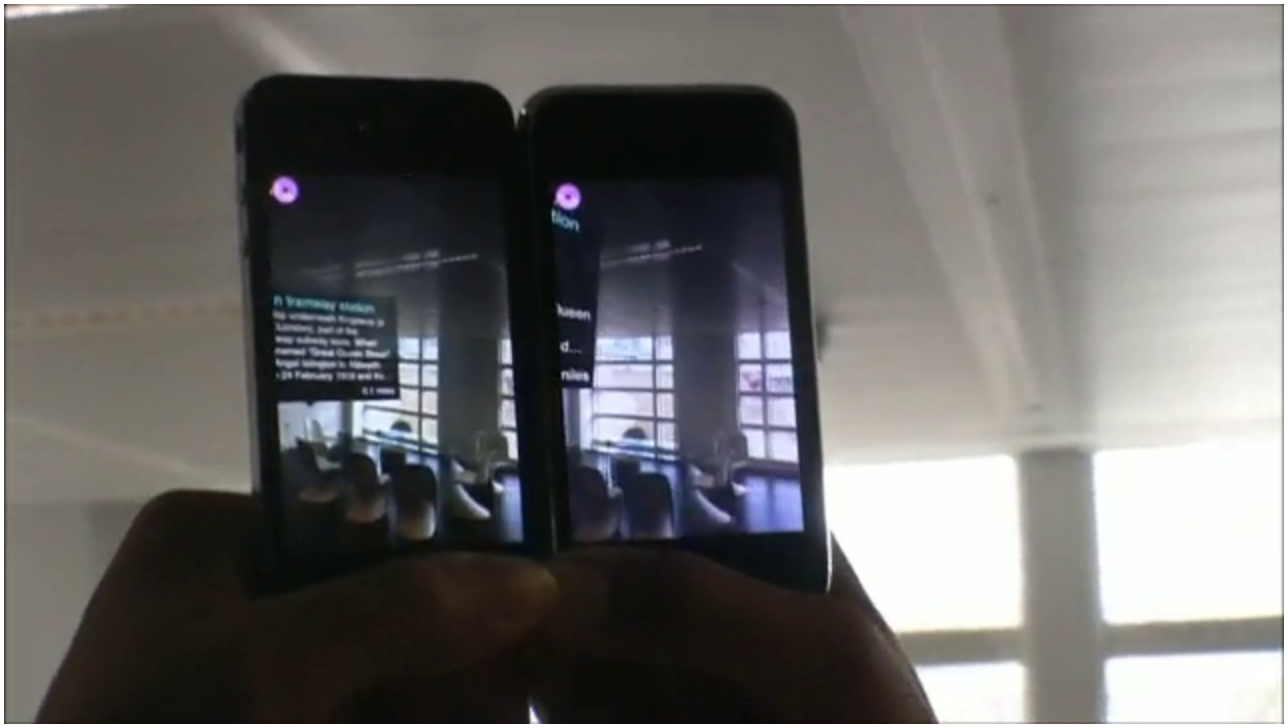
- Features
  - Complete rate gyroscope on a single chip Microelectromechanical systems (MEMS)
  - Z-axis (yaw-rate) response
- Applications
  - GPS navigation systems
  - Image stabilization
  - Inertial measurement units
  - Platform stabilization

Compass-- the Philips KMZ51 magnetic field sensor

- 50/60Hz (high) operation, a jitter of around 1.5˚



Rate gyroscope demo

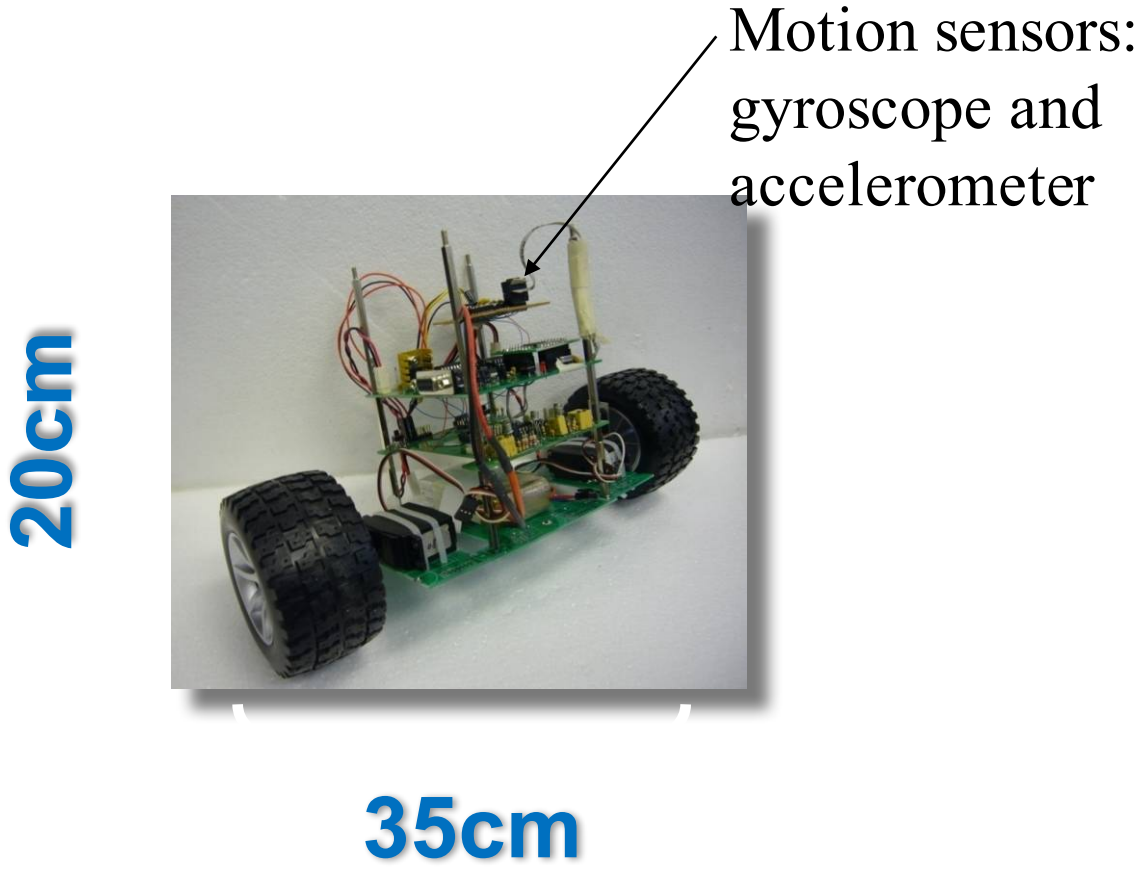


Using Gyroscope compass for virtual reality application in an iphone

http://www.youtube.com/watch?v=VP4-wdMMLFo

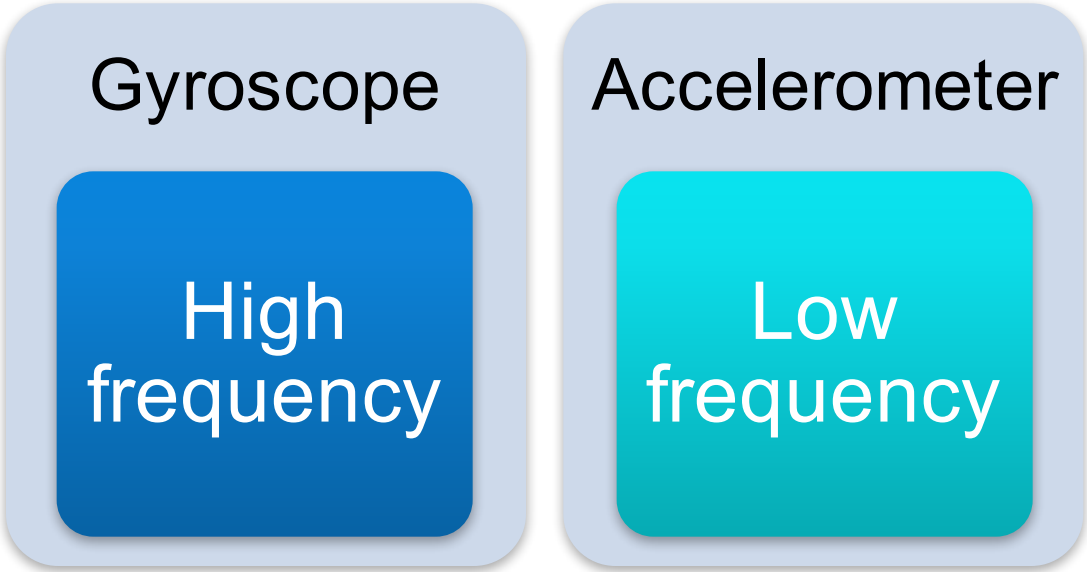
Application of motion sensors
Self balancing robot

- by Kelvin Ko
- http://hk.youtube.com/watch?v=2u-EO2FDFG0



Complementary filter

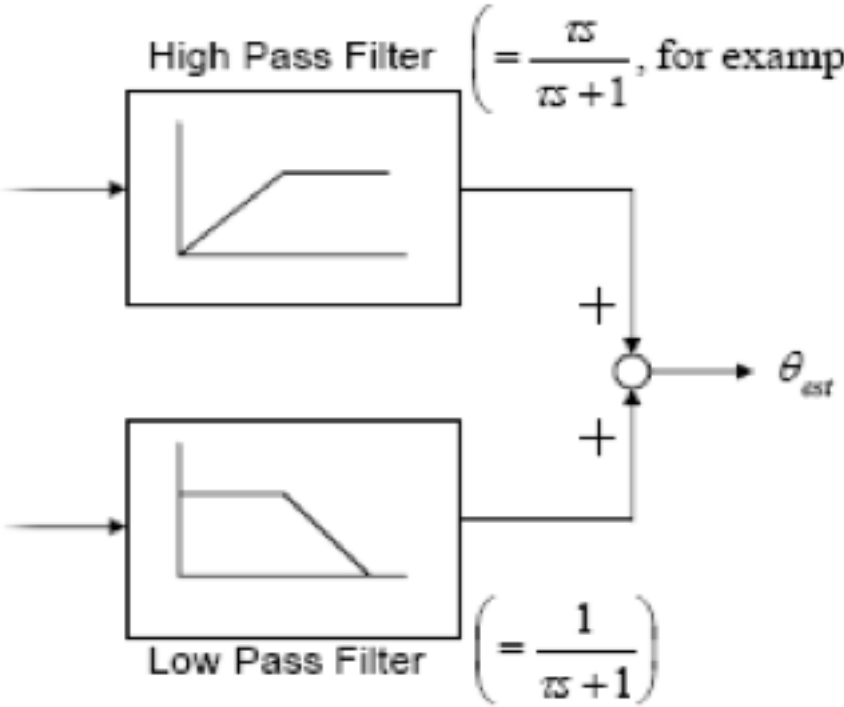
- Since



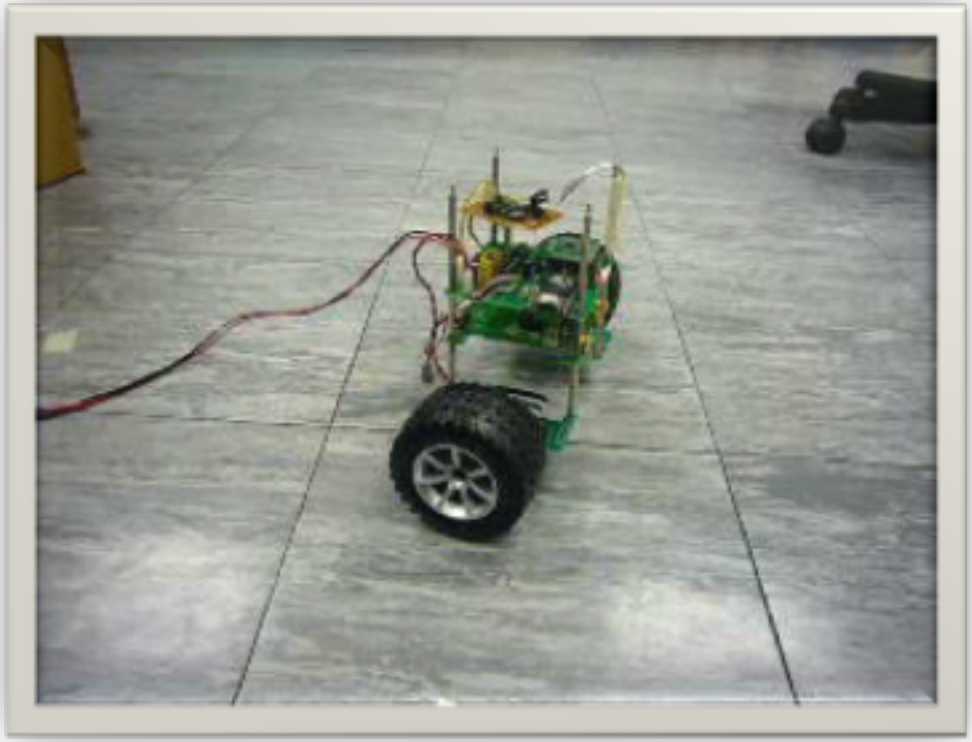
- Combine two sensors to find output

Complementary filter

θ=rotation angle, τ=filter time constant, s=laplace operator

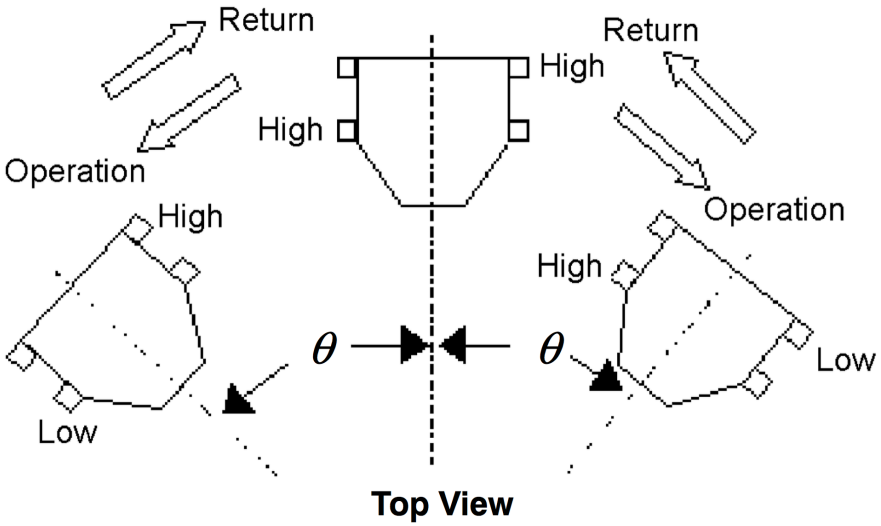


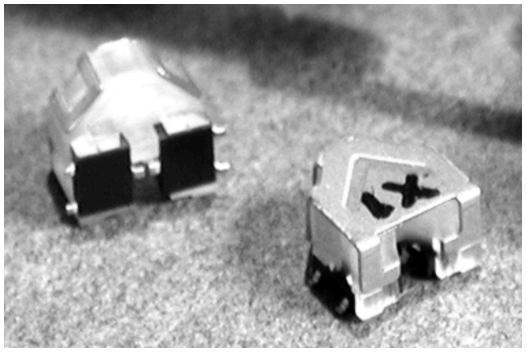
Self Balanced robot using complementary filter



Tilt Sensor by OMRON

- http://rocky.digikey.com/WebLib/Omron%20Web%20Data/D6B.pdf
- Detect tilting 35 ~ 65 degrees in right-and-left inclination





Gravity direction

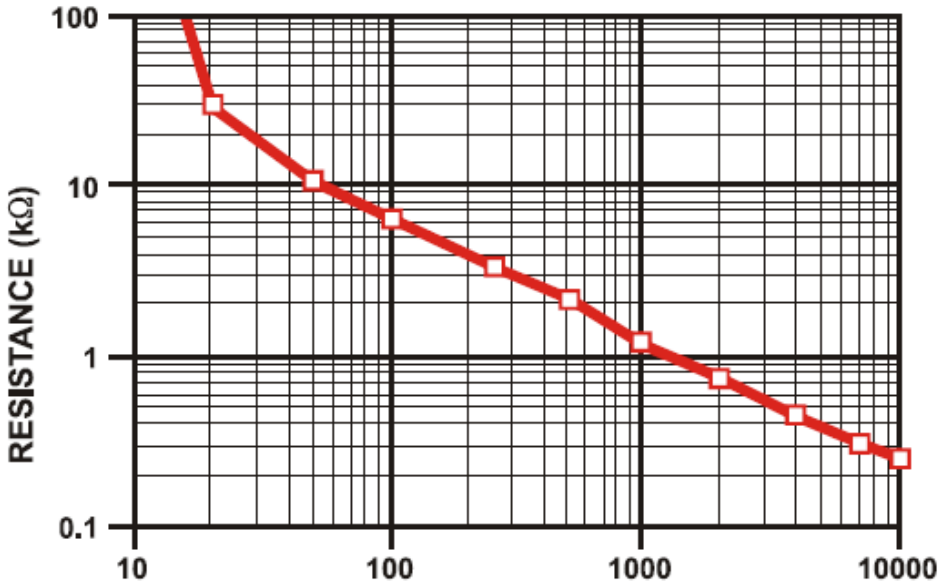
Note: 1. Operation angle: Output goes from High to Low
2. Return angle: Output goes from Low to High

Force/pressure/strain

- Force-sensitive resistor (FSR)
- Strain gauge
- Flexion
- Air pressure

Force Sensing Resistors

- https://www.sparkfun.com/datasheets/Sensors/Pressure/fsrguide.pdf
- FSR402



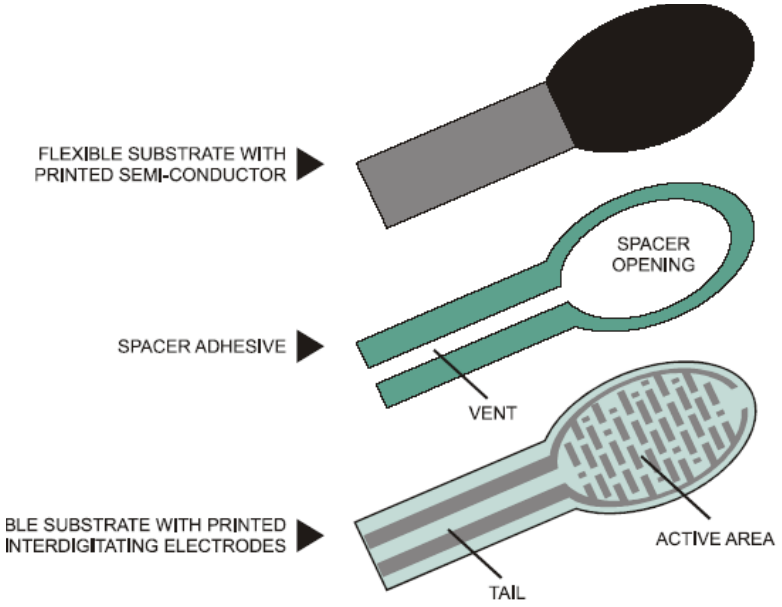
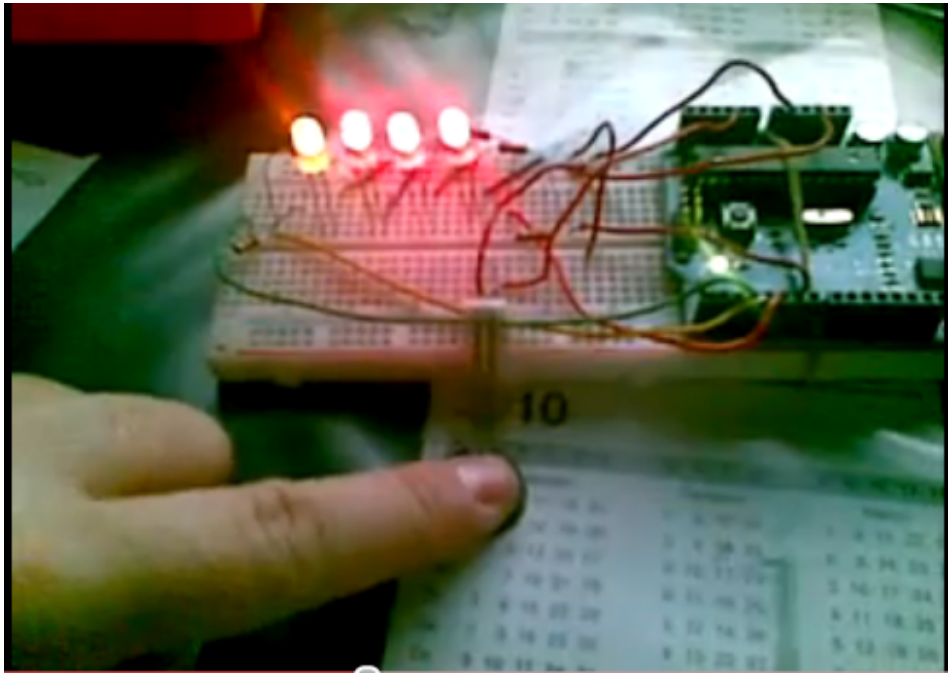


Figure 1: FSR Construction

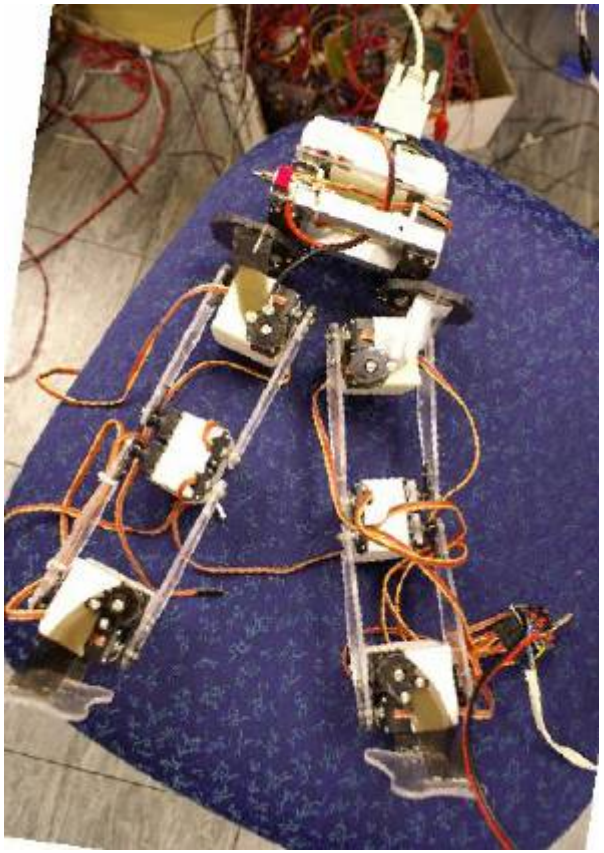
Force Sensing Resistor Demo



http://www.youtube.com/watch?v=LQ21lXr6egs

Application for a walking robot

- Walking robot

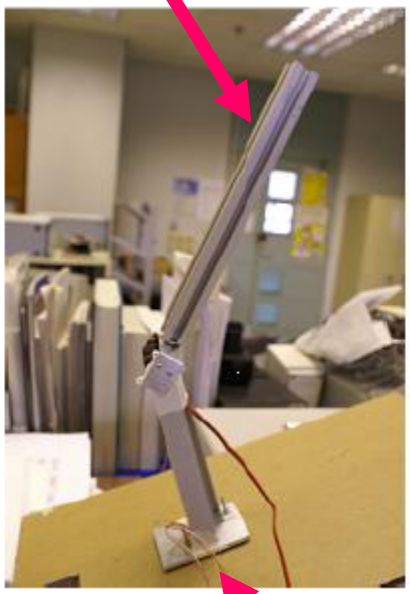


Application of force sensing resistance sensors to balance a walking robot

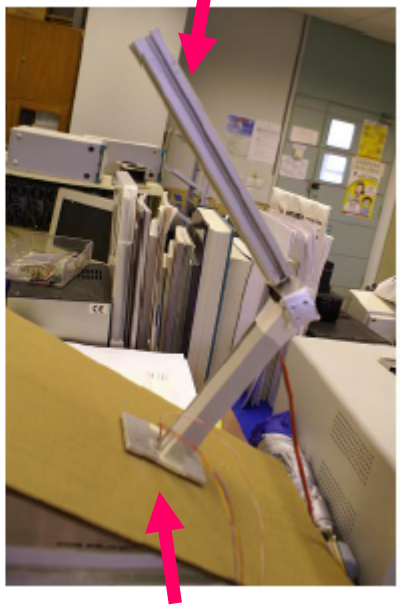
- Balancing

Neutral position

Floor tilled left
upper leg bend right

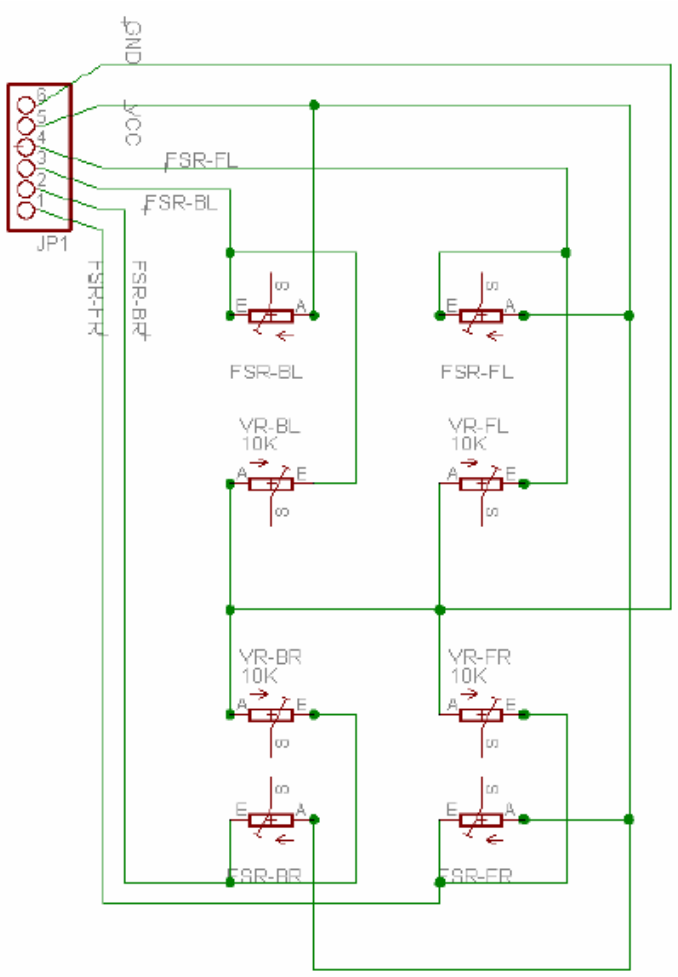


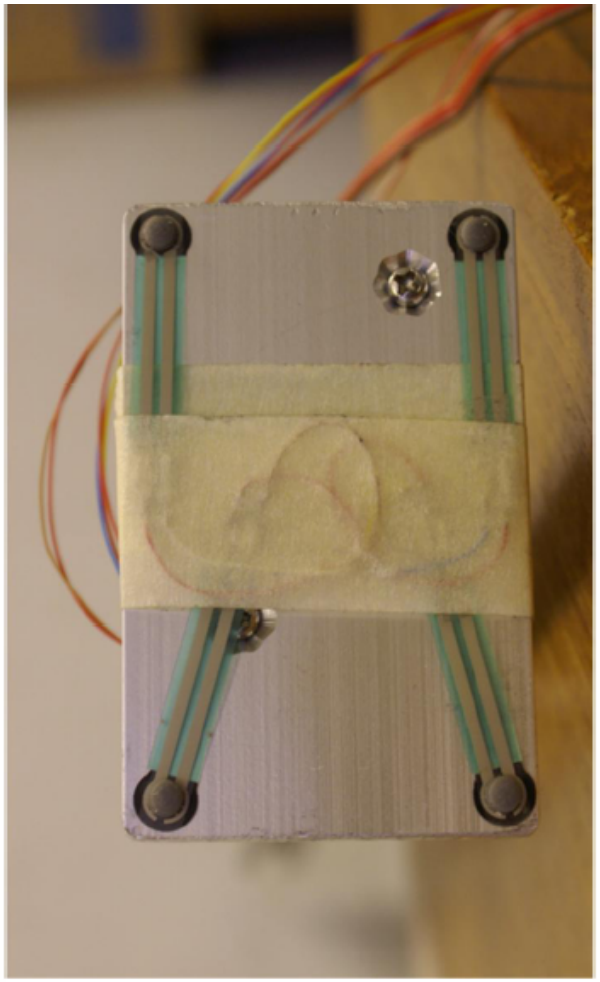
Floor tilled right
upper leg bend left



Four sensors under the foot

Four Force sensors under the foot



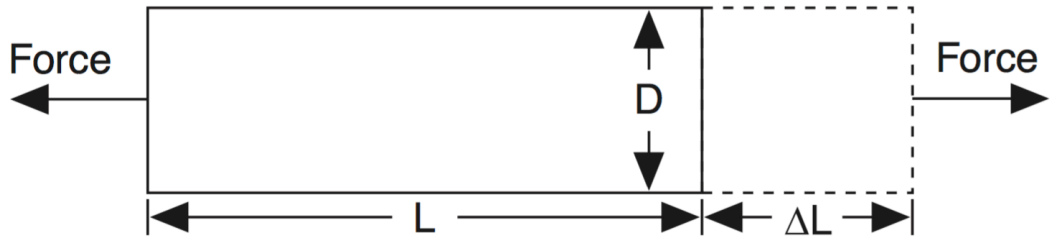


The Nao robot uses force feedback at its feet

- https://en.wikipedia.org/wiki/Nao_(robot)
- http://www.youtube.com/watch?v=2STTNYNF4lk

Strain Gauge : Force sensors

- What's Strain?
  - Amount of deformation of a body due to an applied force.

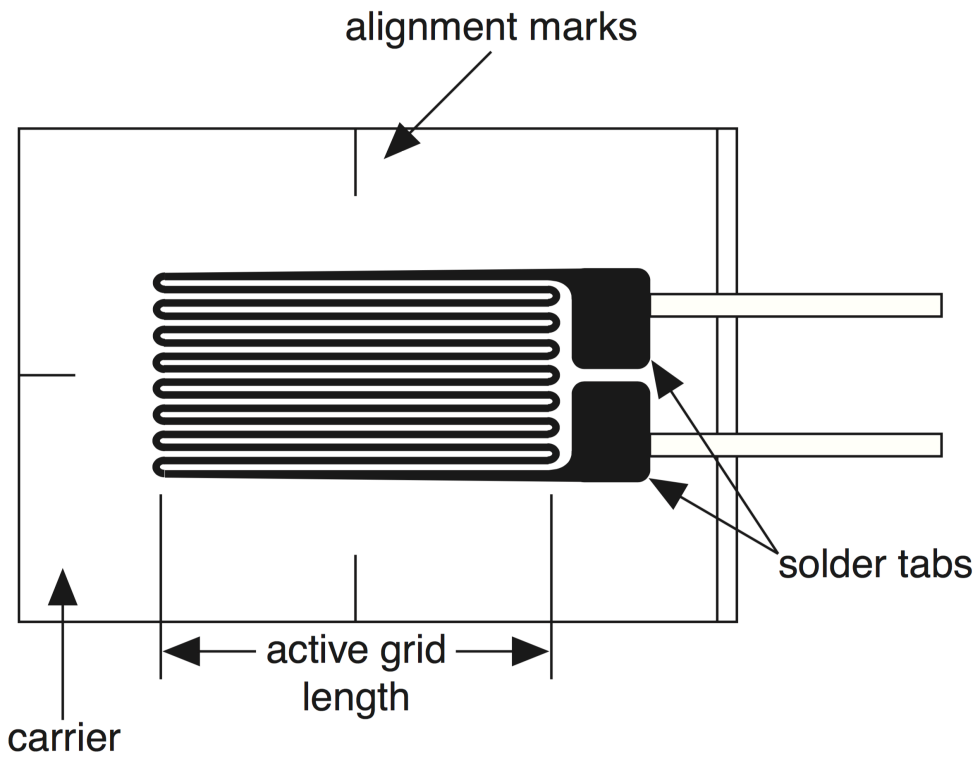


$$\varepsilon = \frac{\Delta L}{L}$$

Figure 1. Definition of Strain

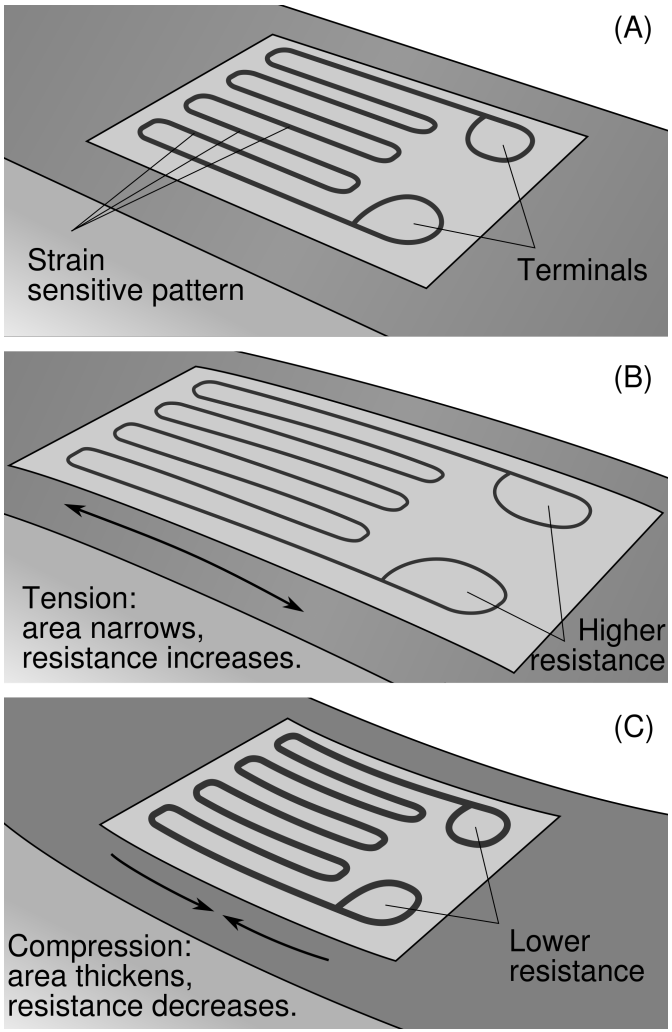
Strain Gauge : Force sensors

- Piezoelectric crystal: produces a voltage that is proportional to force applied
- Strain gauge: cemented on a rod. One end of the rod is fixed, force is applied to the other end. The resistance of the gauge will change with the force.

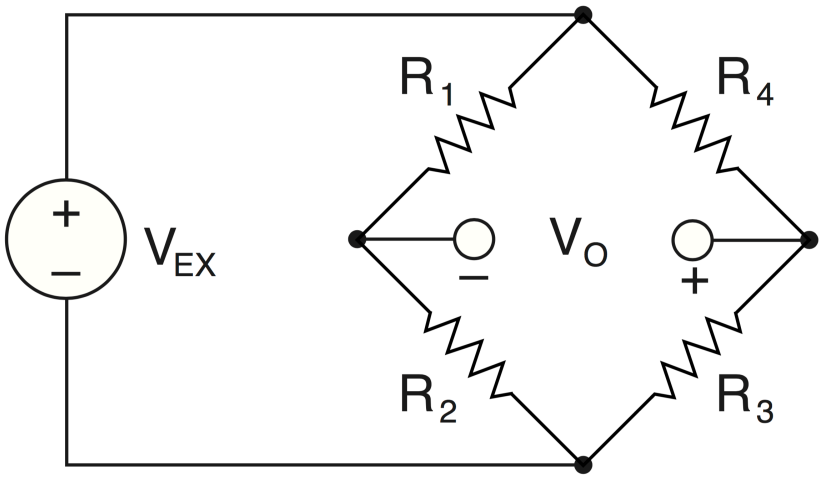


Strain Gauge : Force sensors

- Ex: mechanical strain gauge used to measure the growth of a crack in a masonry foundation.



Wheatstone Bridge

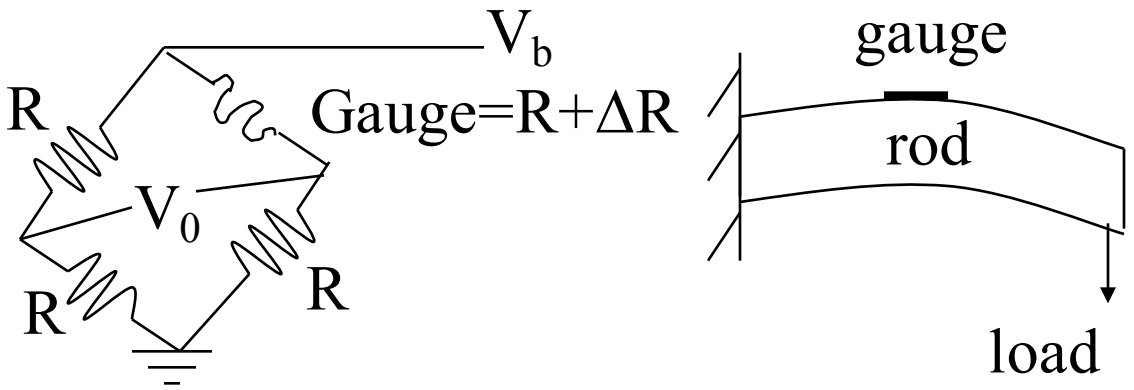


Wheatstone Bridge

$$V_O = \left[\frac{R2}{R1 + R2} - \frac{R3}{R3 + R4}\right] \cdot V_{EX}$$

Single element strain gauge

- sensitive to temperature change.

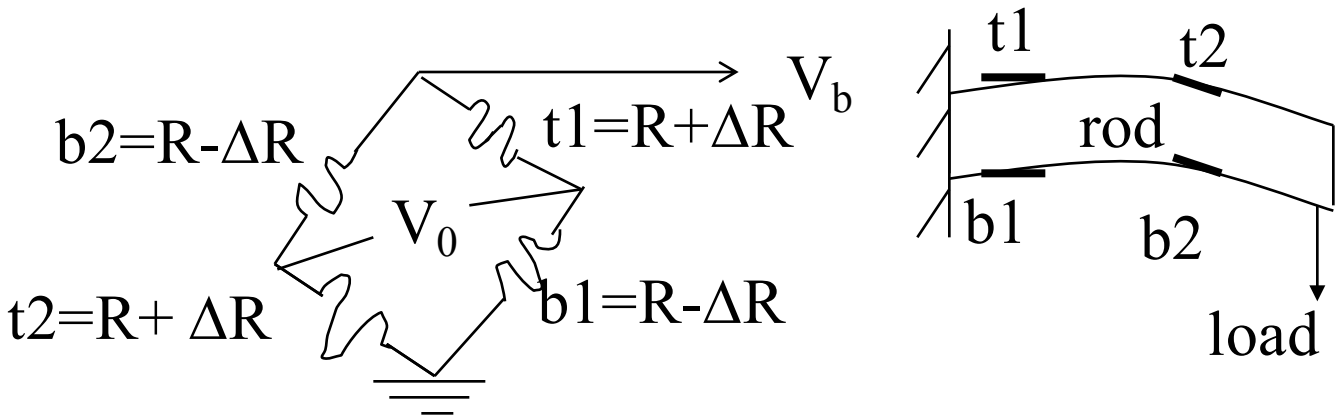


$$V_O = \left[\frac{R}{2R} - \frac{R}{2R+\Delta R}\right] \cdot V_b = \left[\frac{\Delta R}{4R+2\Delta R}\right] \cdot V_b$$

$$\approx \frac{\Delta R}{4R} \cdot V_b$$

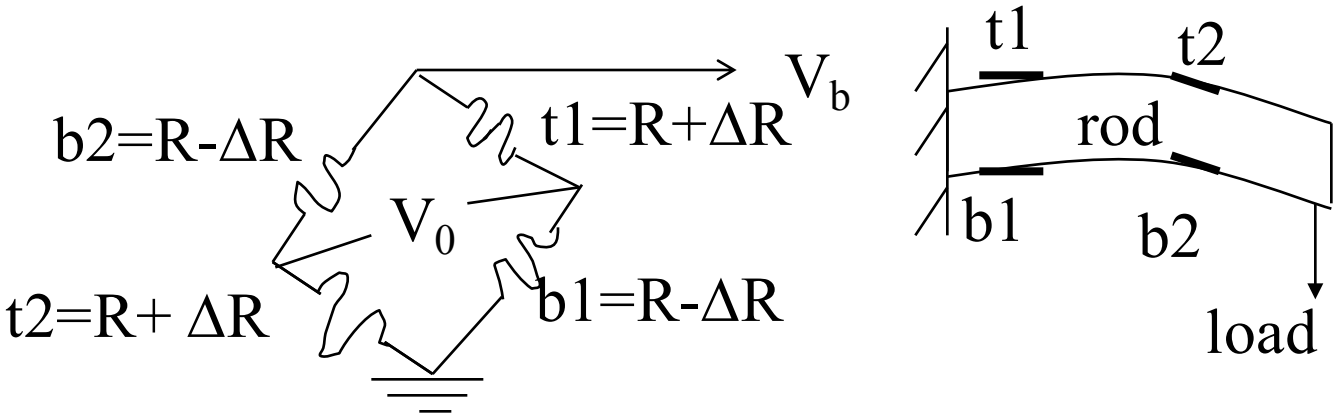
Four-element strain gauge

- Four times more sensitive than single gauge system; not sensitive to temperature change.
- All gauges have unstrained resistance R.



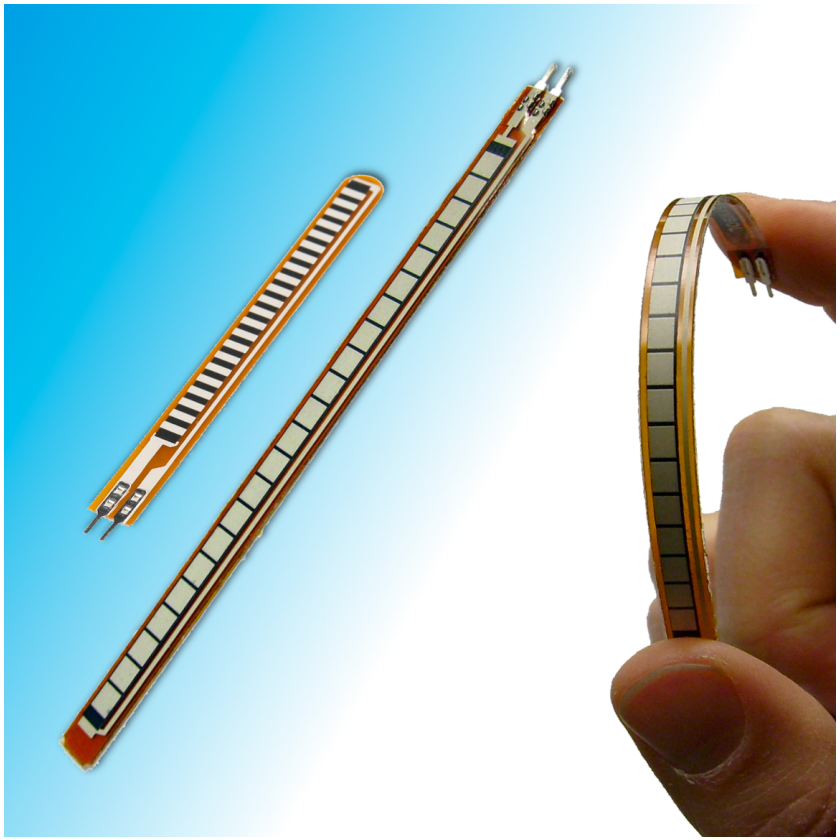
Question

For four-element strain gauge, calculate $\frac{V_O}{V_b}$.



Flexion (bend) sensors

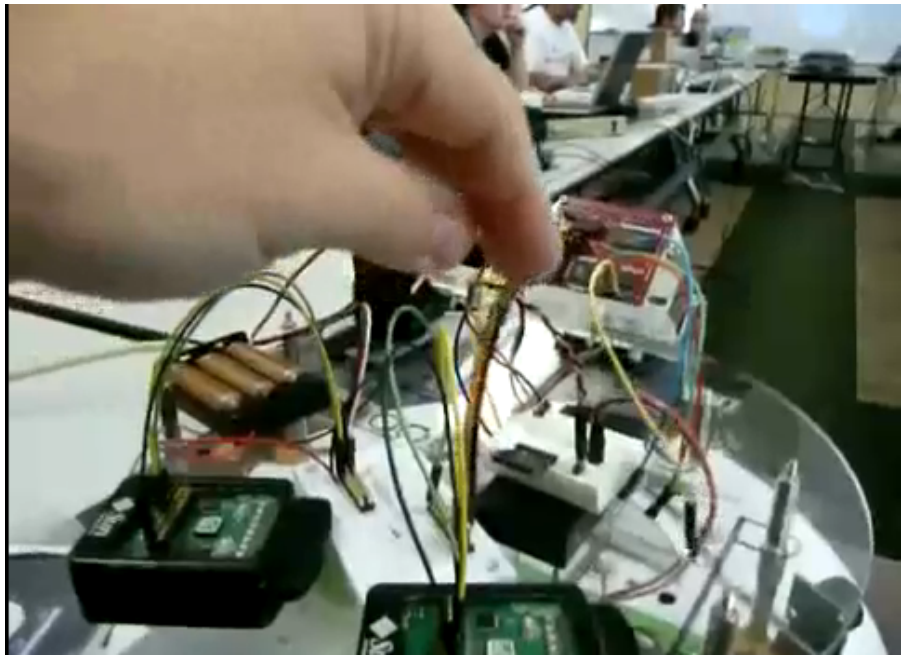
- resistance:
- 10 KΩ (0°);
- 30-40 KΩ (90°)



https://www.youtube.com/watch?v=lEUVlSsAhCg

http://www.jameco.com/Jameco/Products/ProdDS/150551.pdf

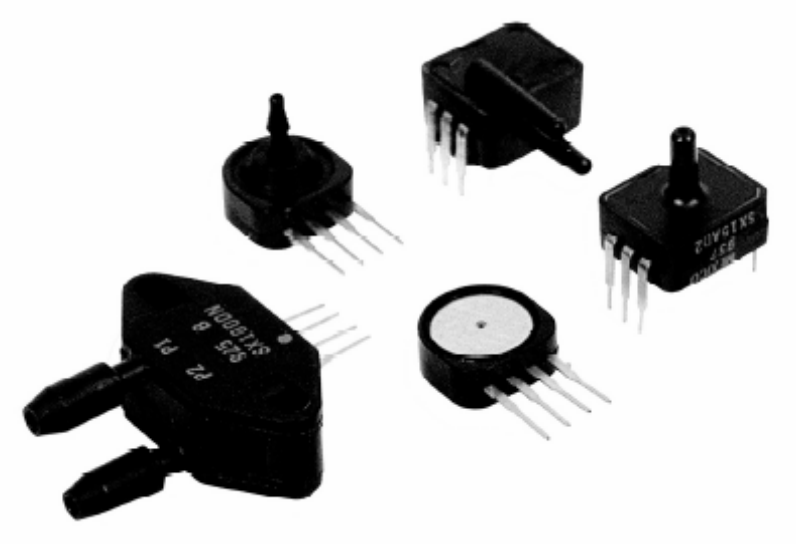
Felixon resistance Demo



http://www.youtube.com/watch?v=m4E5SP7HCnk&feature=related

Air pressure sensor

- Measure up to 150 psi (pressure per square inch).

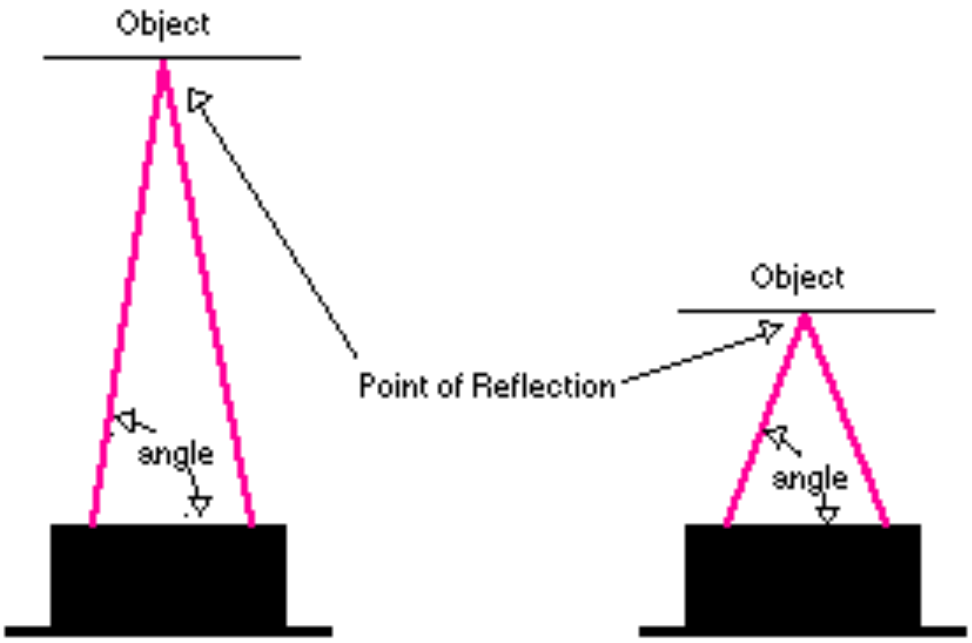


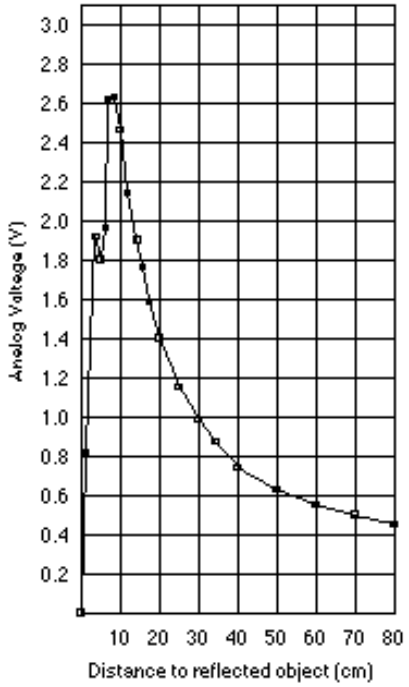
Position sensors

- Infra-red range sensor
- Linear and Rotary position sensors

Infra-red Range detectors by SHARP (4 to 30cm)

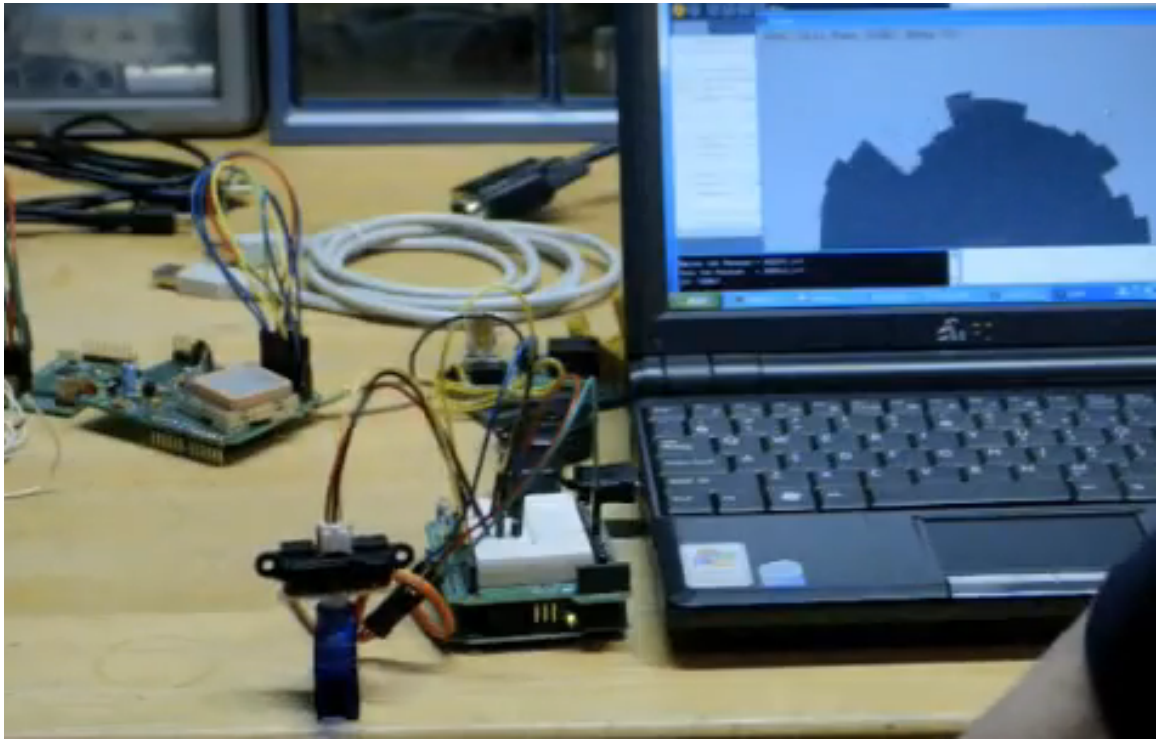
- An emitter sends out light pulses. A small linear CCD array receives reflected light.
- The distance corresponds to the triangle formed.





http://www.acroname.com/robotics/info/articles/sharp/sharp.html

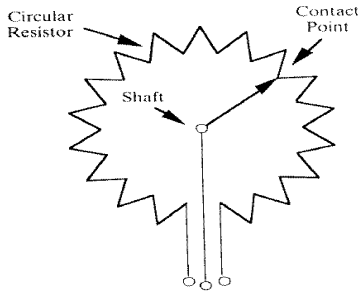
IR radar using the Sharp range detector

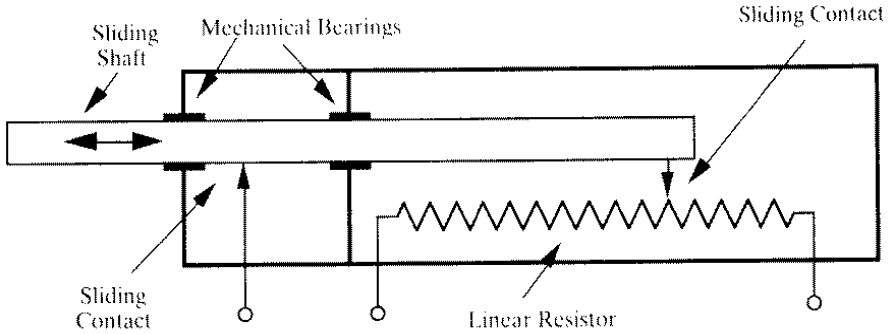


http://www.youtube.com/watch?v=tStBLAiQaC8&feature=related

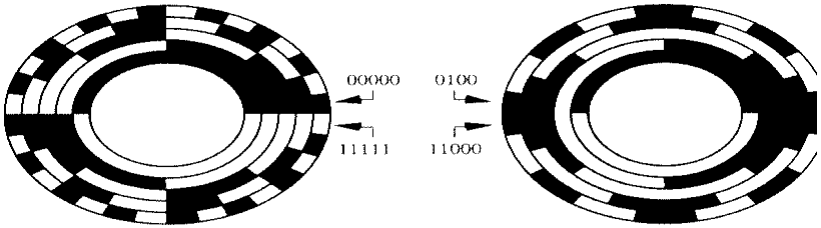
Position sensors, from [1]

- Rotary





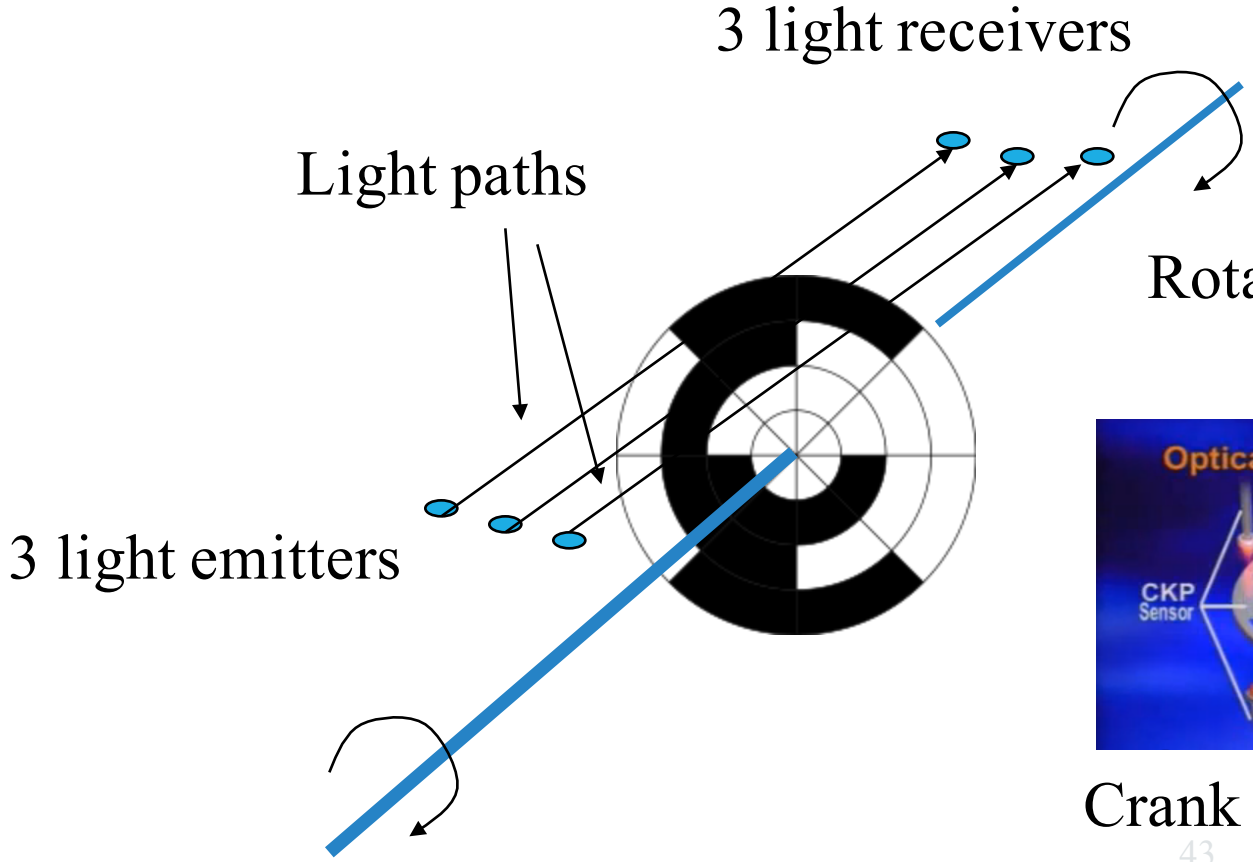
- Rotary Encoder

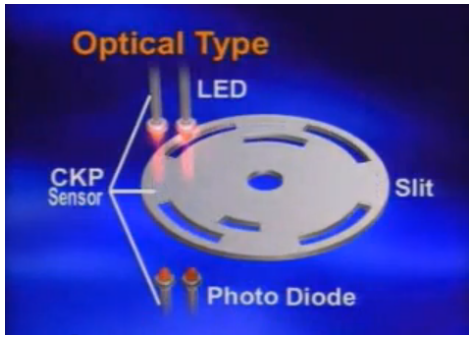


- Digital Linear Encoder

Optical rotary encoder

- http://en.wikipedia.org/wiki/Rotary_encoder
- https://www.youtube.com/watch?v=RuIisITGOwA
- The light received (on or off) will tell the rotation angle)





Crank shaft sensor

Magnetic rotary encoder

- http://www.renishaw.com/en/magnetic-rotary-encoders--9801
- Non touch sensing

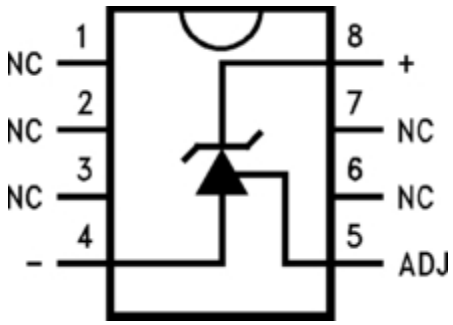
Temperature and humidity

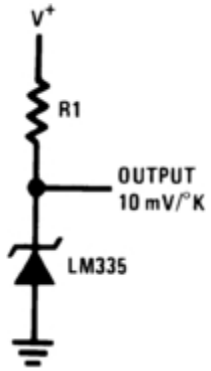
- Temperature
- humidity

Temperature sensors

http://www.ti.com/product/LM135

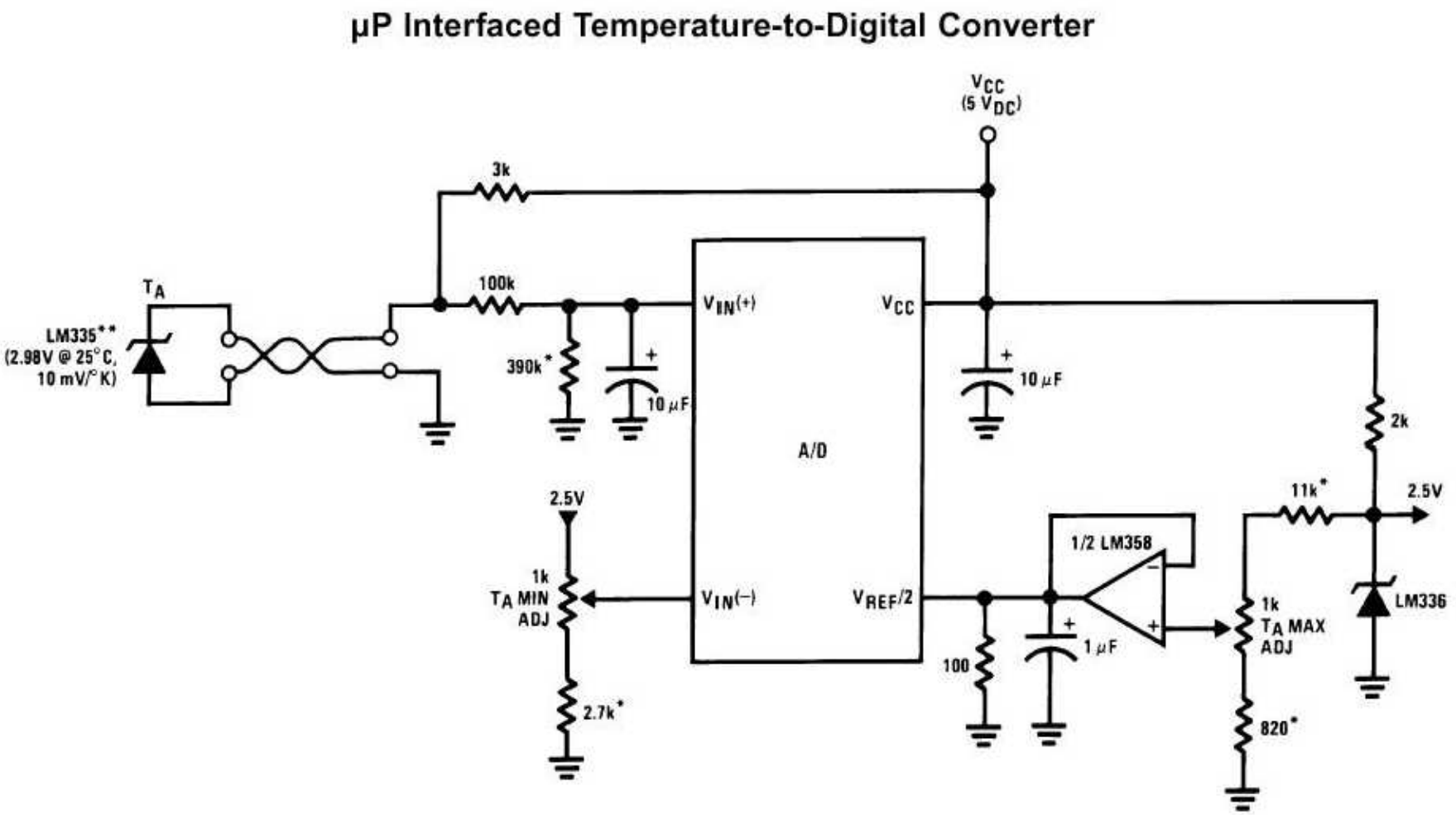
- Directly calibrated in ° Kelvin
- 1° C initial accuracy available
- Operates from 400 μA to 5 mA
- Less than 1 Ohm dynamic impedance
- Easily calibrated
- Wide operating temperature range
- 200° C over range
- Low cost





Application note

- (connecting to an ADC e.g. ADC0820 or ADC0801)



Humidity Sensor

http://rocky.digikey.com/WebLib/BC%20Components/Web%20Data/2322%20691%2090001.pdf

- Humidity range (RH) -> Capacitance
- **BCcomponents 2322 691 90001**
  10-90%RH Dc

QUICK REFERENCE DATA

PARAMETER	VALUE	UNIT
Humidity range (RH)	10 to 90	%
Capacitance at +25 °C; 43% RH; 100 kHz	122 ±15%	pF
Sensitivity between 12 and 75% RH	0.4 ±0.05	pF/%RH
Frequency	1 to 1000	kHz
Maximum AC or DC voltage	15	V

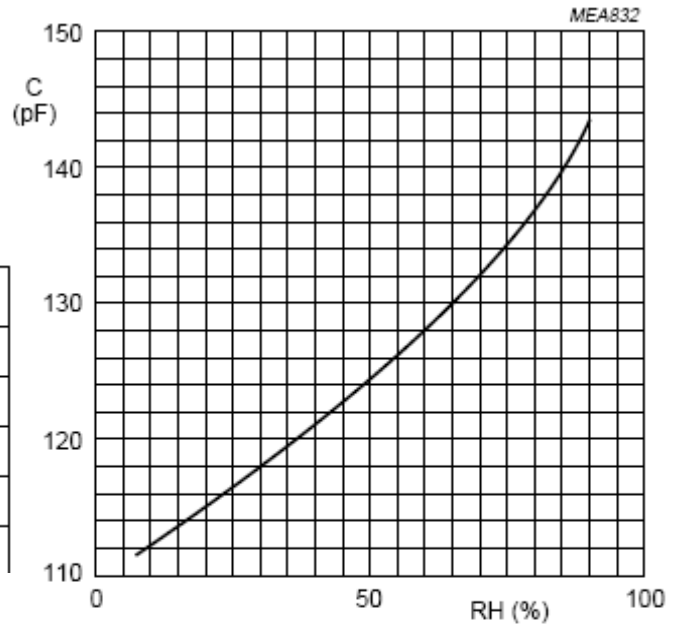
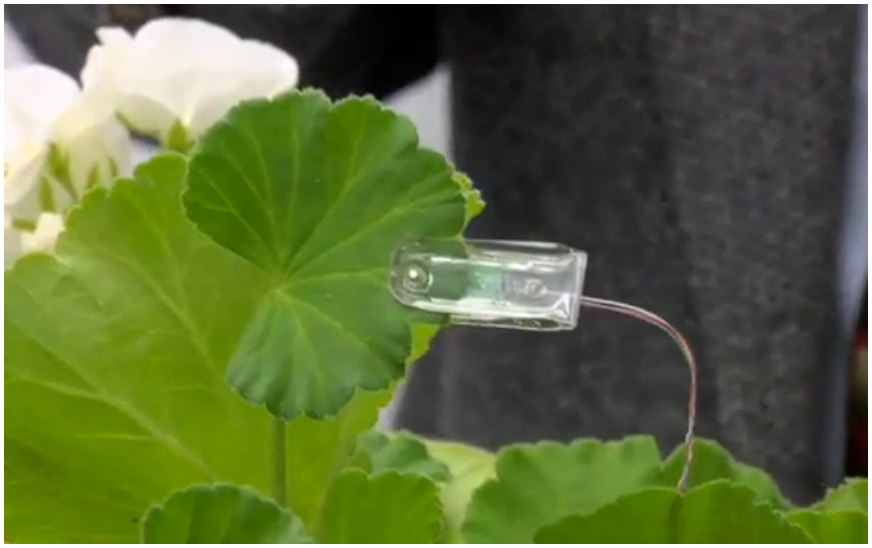


Fig.2 Typical capacitance as a function of relative humidity.

Leaf Sensor Alerts When Plants Are Thirsty

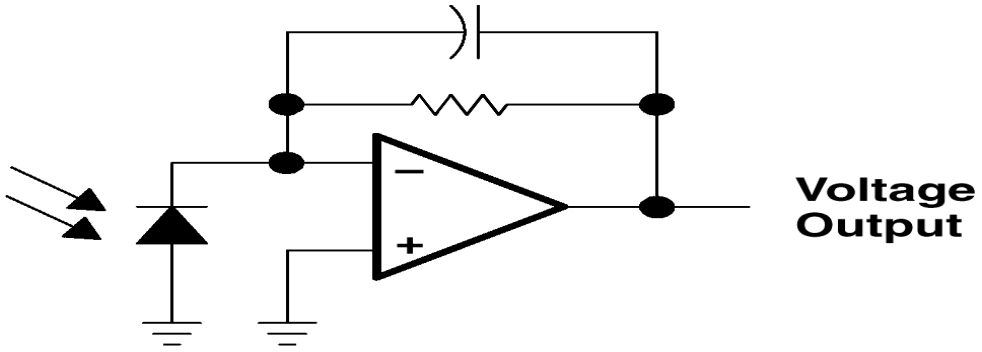


http://www.youtube.com/watch?v=VM4X_fqPPco

LIGHT-TO-VOLTAGE OPTICAL SENSORS

http://www.ti.com/lit/ds/symlink/tsl250.pdf

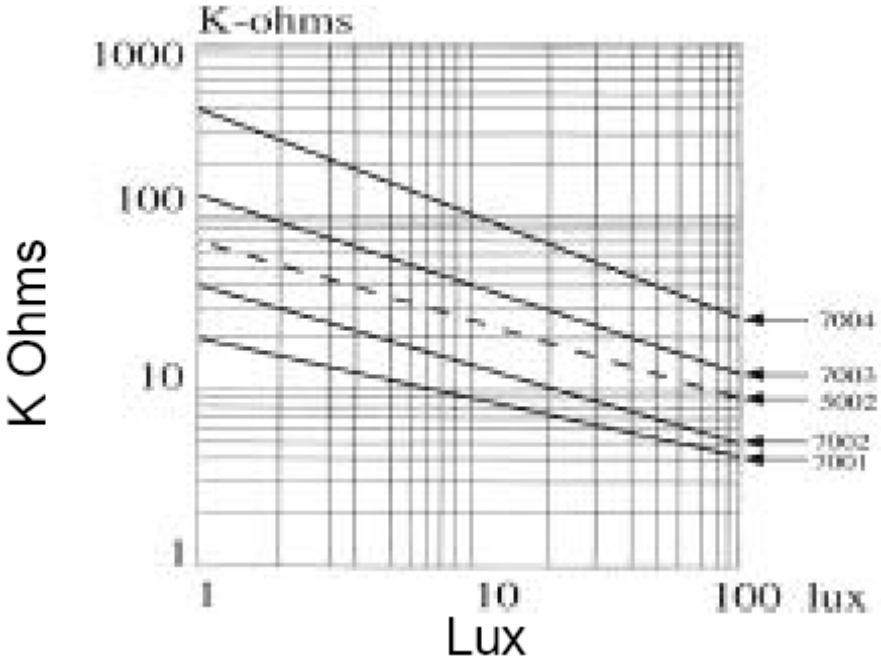
- Light-to-voltage optical sensors, each combining a **photodiode** and an amplifier (feedback resistor = 16 MW, 8 MW, and 2 MW respectively).
- The output voltage is directly proportional to the light intensity on the photodiode.



Cadmium Sulfoselenide (CdS) Photoconductive Photocells

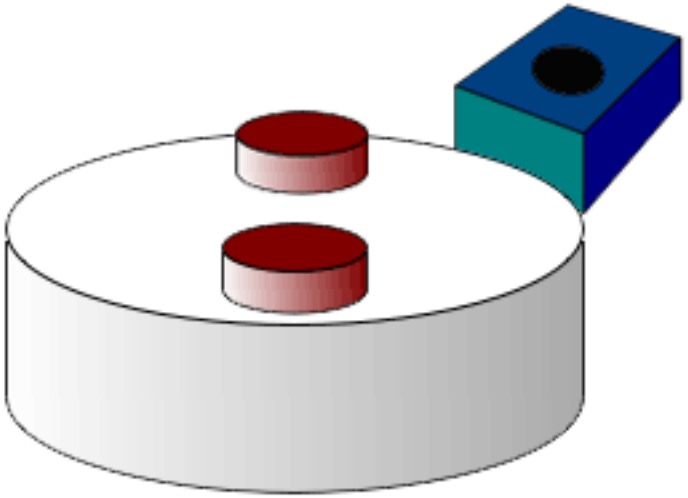
http://faculty.uml.edu/yluo/Teaching/MicroprocessorII/resources/pdvp5001.pdf

- Light sensing using CdS



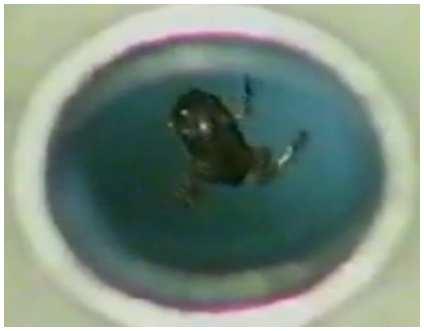
Hall effect Sensors

- voltage difference across an electrical conductor, transverse to an electric current
- A wheel containing two magnets passing by a Hall effect sensor



Application on Magnetic levitation 磁懸浮

Magnetic levitation Train Model
磁懸浮火車
http://www.youtube.com/watch?v=TeS_U9qFg7Y



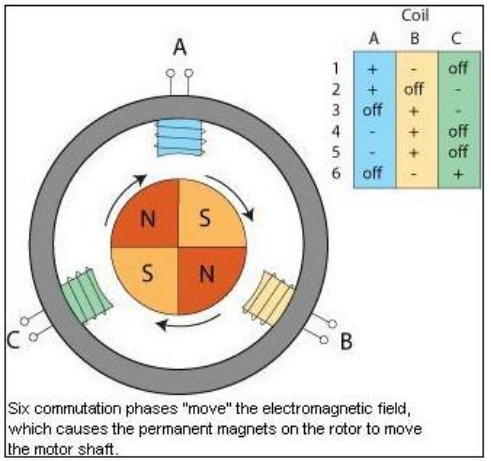
frog levitation
http://www.youtube.com/watch?v=A1vyB-O5i6E

http://www.youtube.com/watch?v=XjjBqzilkIc

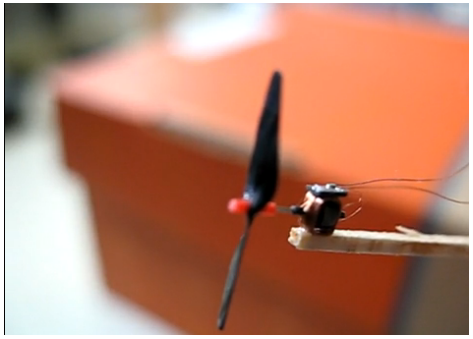
Hall effect sensors and brushless DC motors

- Brushless DC motor

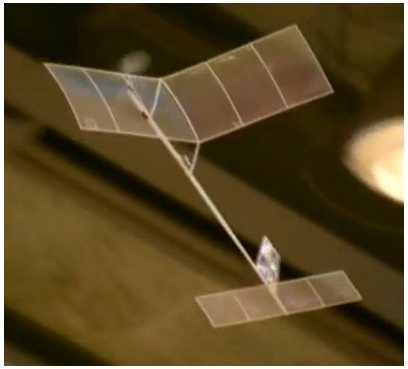
https://www.youtube.com/watch?v=bCEiOnuODac



- Is it using Hall effect sensor? Don't known.



http://www.youtube.com/watch?v=cm0h2Qf3upQ

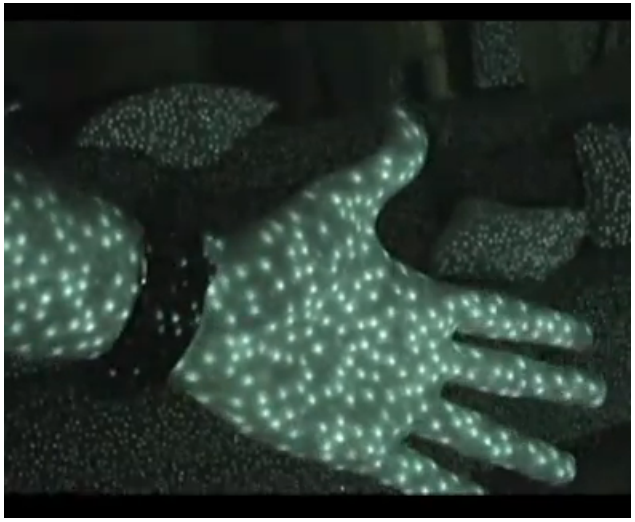


http://www.youtube.com/watch?v=JmRkxZT4XhY

Novel sensors

- Kinect

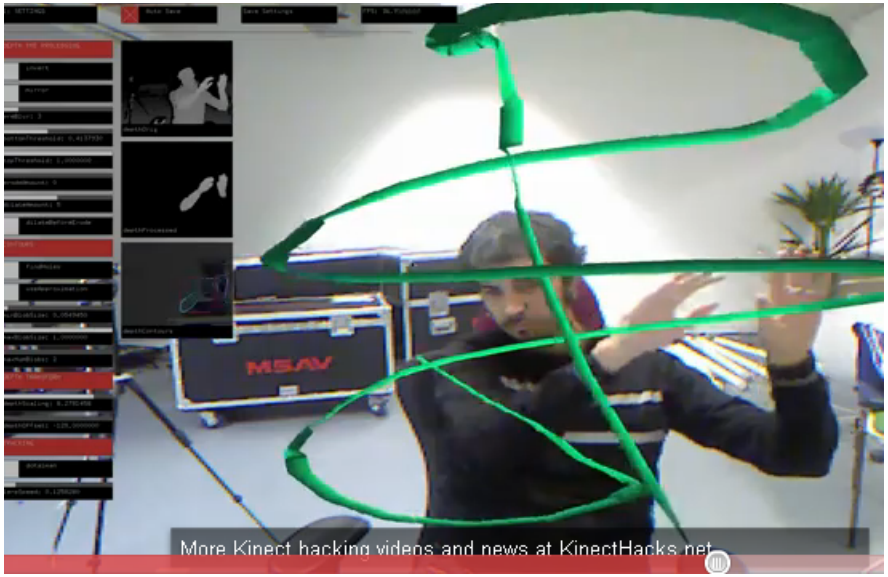
https://learn.adafruit.com/hacking-the-kinect

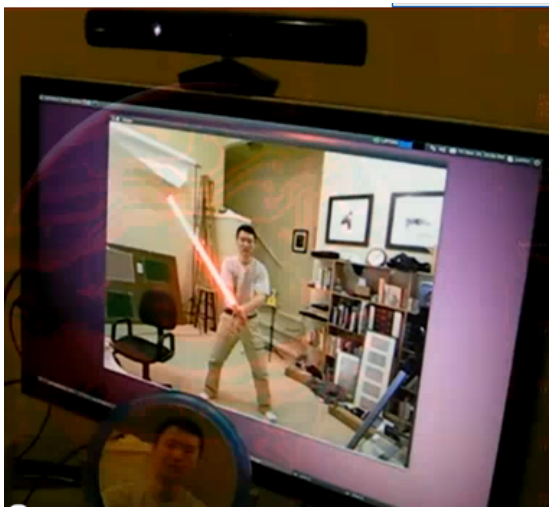


http://www.youtube.com/watch?v=nvvQJxgykcU

https://www.youtube.com/watch?v=p2qlHoxPioM

Many KINECT DIY projects





http://www.youtube.com/watch?v=Brpu30vjCa4&feature=related

Summary

- Studied the characteristics of various sensors
- and their applications