CENG4480

Lecture 05: Sensors

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The Chinese University of Hong Kong

Overview

1. Motion Sensors
    1-1. Accelerometer
    1-2. Gyroscope
    1-3. Compass
    1-4. Tilt Sensor
2. Force Sensors
    2-1. Force Sensing Resistor
    2-2. Strain Gauge
    2-3. Flexion (bend) sensors
    2-4. Air Pressure Sensor
3. Other Sensors
    3-1. Position sensors
    3-2. Temperature and humidity
    3-3. Optical Sensors
    3-4. Hall Effect Sensors
    3-5. Kinect Sensors

Overview

1-1. 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
  - measure acceleration in one or more directions, position can be deduced by integration.
- Methods:
  - Mass spring method ADXL78 (from Analog Device)
  - Air pocket method (MX2125)

ADXL78 (Mass Spring Method)

- Click this online document
- Measure the capacitance to create output
- Measure both dynamic & static acceleration

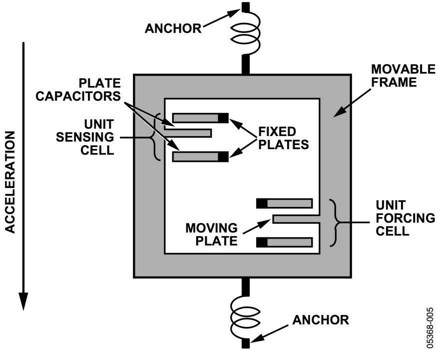


Figure 5. Simplified View of Sensor Under Acceleration

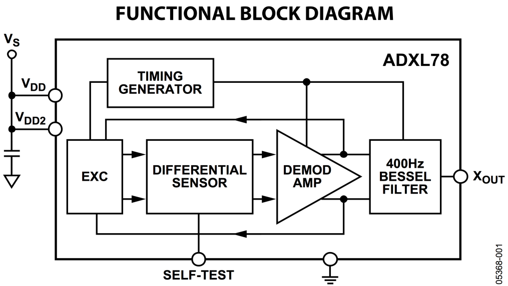


Figure 1.

ADXL330 Accelerometer for (X, Y, Z) Directions

- Clik this online document
- 3D

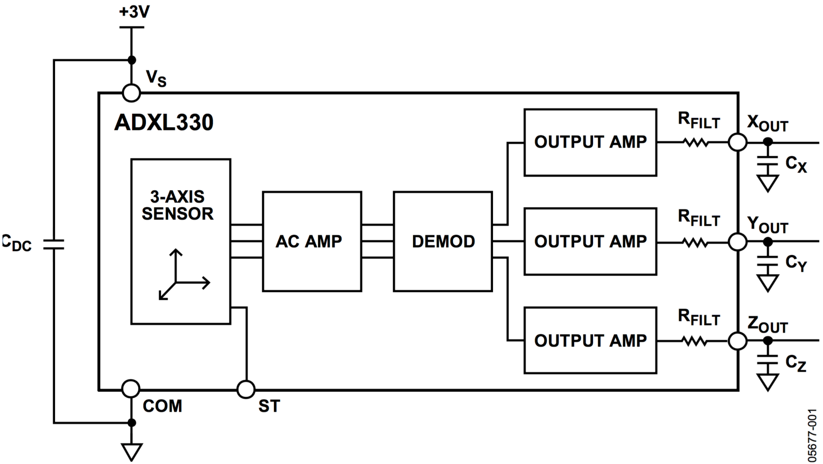
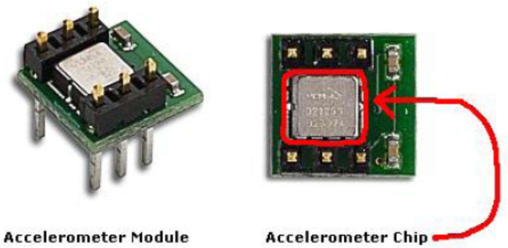
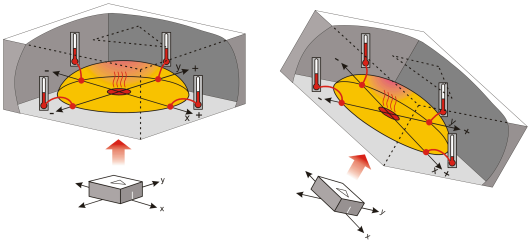


Figure 1.

2D Translational Accelerometer MX2125

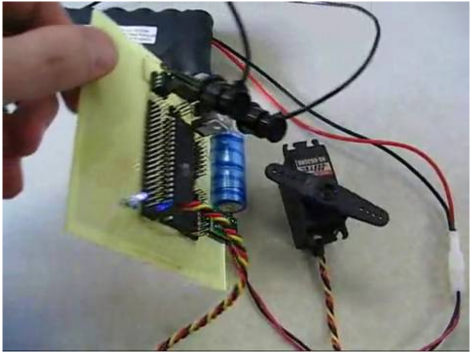
- Clik this online document
- Gas pocket type





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

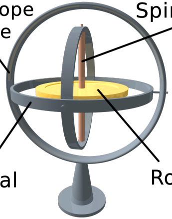
Demo: orientation sensing



(https://youtu.be/9NEiBDBXFEQ)

1-2. Gyroscopes

- wiki page
- 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

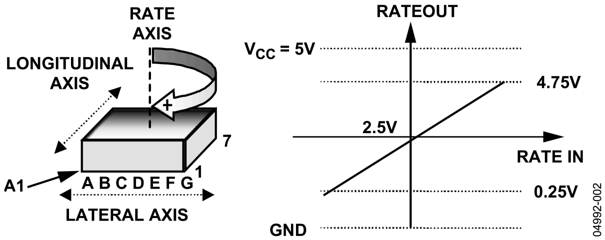


Figure 2. RATEOUT Signal Increases with Clockwise Rotation

Features

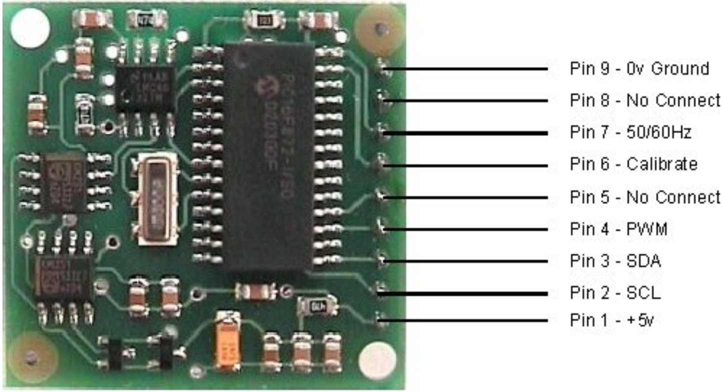
- Complete rate gyroscope on a single chip Microelectromechanical systems (MEMS)
- Z-axis (yaw-rate) response

Applications

- GPS navigation systems
- Image stabilization
- Inertial measurement units
- Platform stabilization

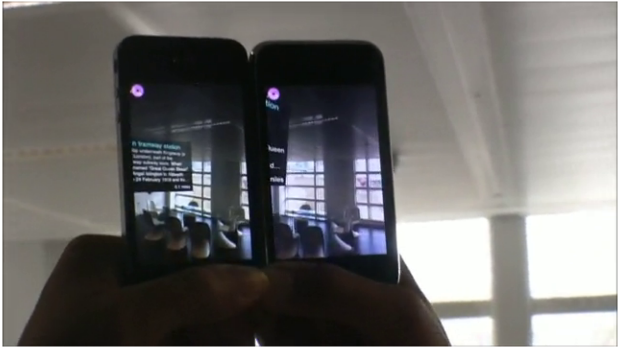
1-3. Compass

- Philips `KMZ51` magnetic field sensor
- 50/60Hz (high) operation, a jitter of around 1.5°



Rate gyroscope demo

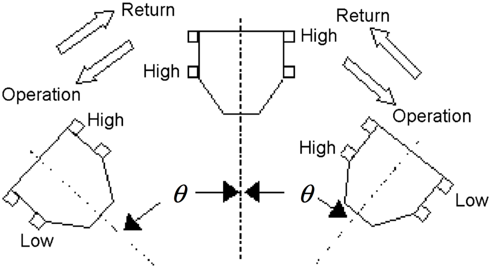
Using Gyroscope compass for virtual reality application in an iphone

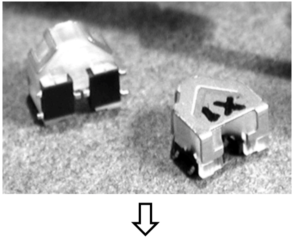


(https://youtu.be/VP4-wdMMLFo)

1-4. Tilt Sensor by OMRON

- Click this online document
- Detect tilting $35 \sim 65$ degrees in right-and-left inclination





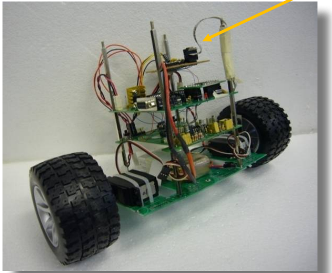
Note: 1. Operation angle: Output goes from High to Low
2. Return angle: Output goes from Low to High

Demo: Tilt Sensing

(https://youtu.be/C6uVrYz-j70)

One more reference: https://youtu.be/KZVgKu6v808.

Application – Self Balancing Robot



Motion sensors: gyroscope and accelerometer

20cm

35cm

by Kelvin Ko (https://youtu.be/2u-EO2FDFG0)

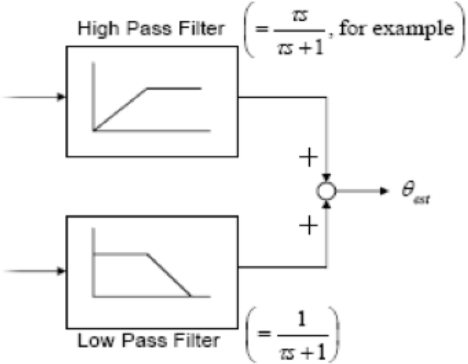
Complementary Filter

- Since

Gyroscope	Accelerometer
High frequency	Low frequency

- Combine two sensors to find output

Complementary Filter (cont.)

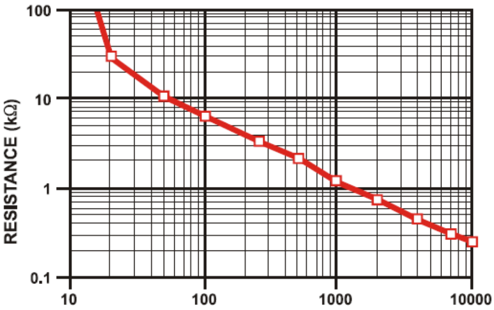


- θ: rotation angle
- τ: filter time constant
- s: Laplance operator

Overview

2-1. Force Sensing Resistors

- FSR402
- Exhibits a decrease in resistance with an increase in the force applied to the active surface.
- Click this online document



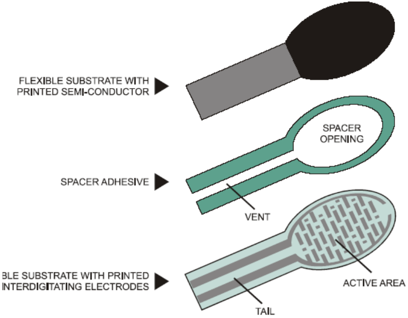
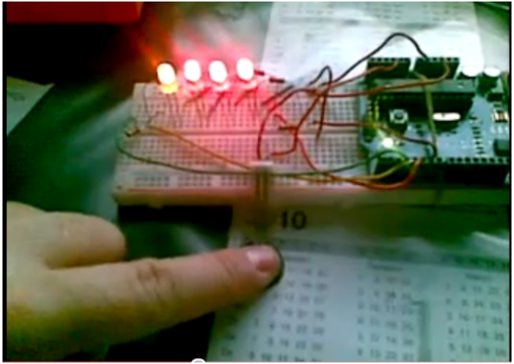


Figure 1: FSR Construction

Force Sensing Resistor Demo



(https://youtu.be/LQ21lXr6egs)

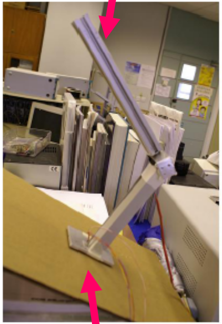
Application 1: Walking Robot

- Balancing

Neutral position

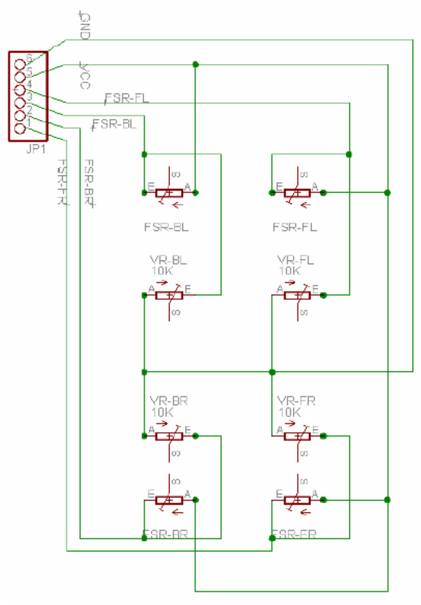
Floor tilled left
upper leg bend right

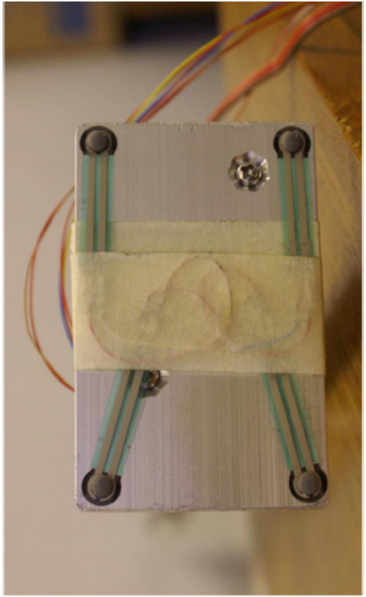
Floor tilled right
upper leg bend left



Four sensors under the foot

Four Force sensors under the foot





Application 2: The Nao Robot

- uses force feedback at its feet
- wiki page

(https://youtu.be/2STTNYNF4lk)

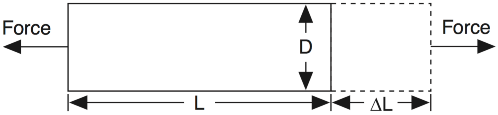
Application 3: Robot Dog from Boston Dynamics

(https://youtu.be/wXxrmussq4E)

2-2. Strain Gauge

What's Strain?

Amount of deformation of a body due to an applied force.

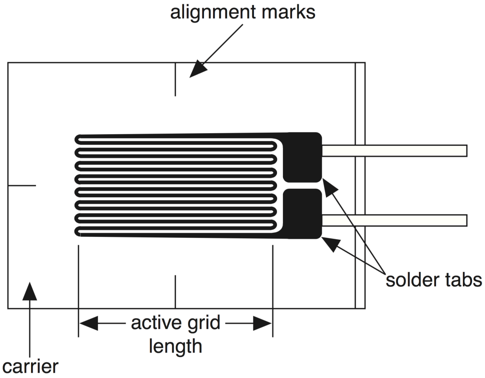


$$\varepsilon = \frac{\Delta L}{L}$$

Figure 1. Definition of Strain

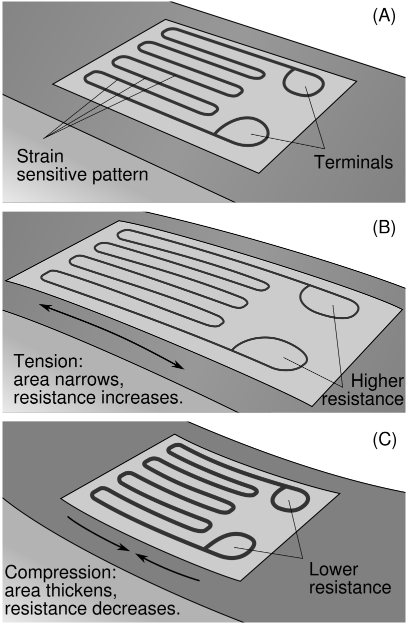
Strain Gauge (cont.)

- Piezoelectric crystal: produces a voltage that is proportional to force applied
- Strain gauge: a device for indicating the strain of a material or structure at the point of attachment
- 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.

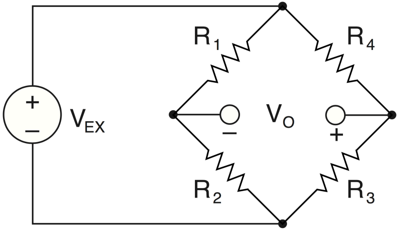


Strain Gauge (cont.)

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



Wheatstone Bridge

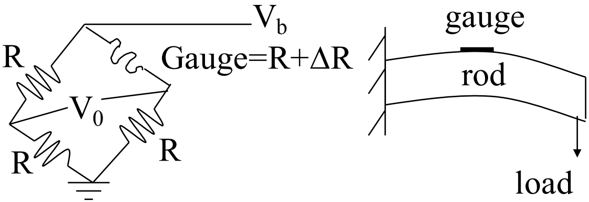


Wheatstone Bridge

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

Single Element Strain Gauge

Sensitive to temperature change.

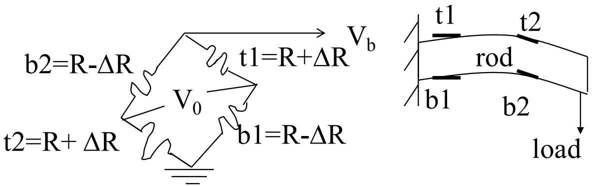


Out Voltage

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

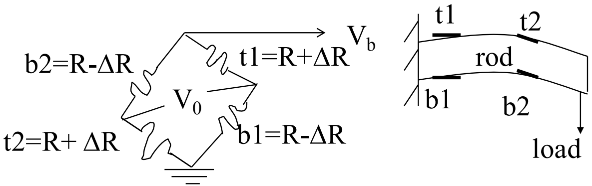
Four-Element Strain Gauge

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

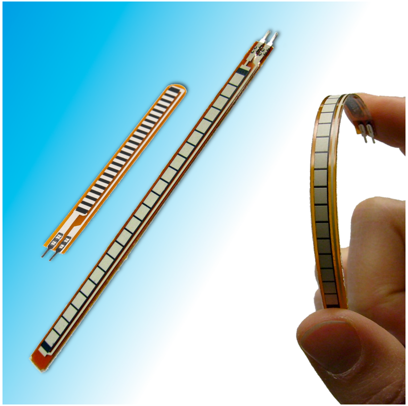


Question

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



2-3. Flexion (bend) sensors



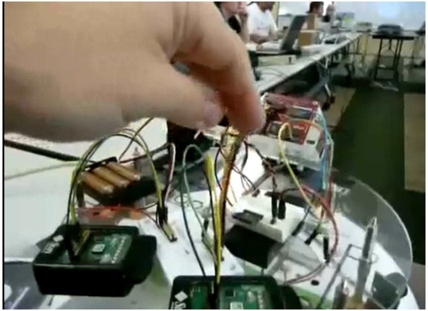
Resistance:

- 10 KΩ (0°);
- 30–40 KΩ (90°)

https://youtu.be/lEUVlSsAhCg

Click this online document

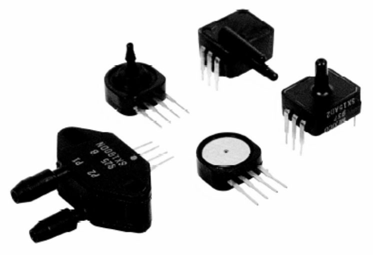
Felixon resistance Demo



(https://youtu.be/m4E5SP7HCnk)

2-4. Air Pressure Sensor

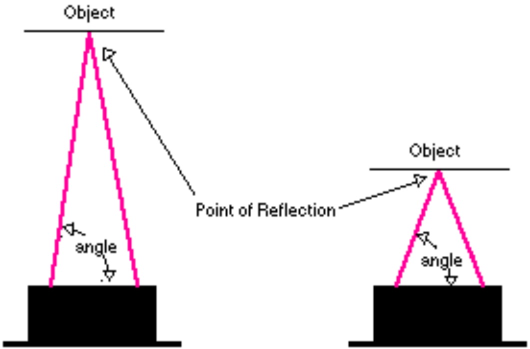
- Measure up to 150 psi (pressure per square inch).

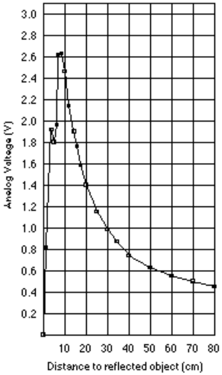


Overview

Infra-red Range detectors

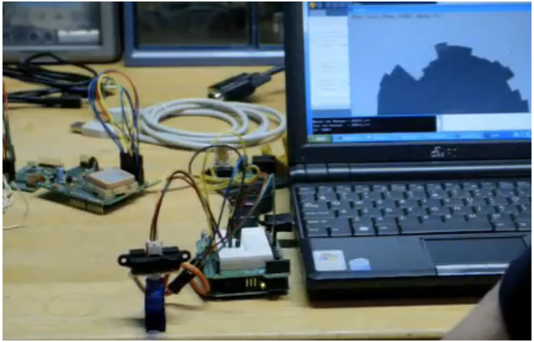
- by SHARP (4 to 30 cm)
- An emitter sends out light pulses. A small linear CCD array receives reflected light.
- The distance corresponds to the triangle formed.





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

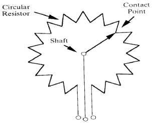
IR radar using the Sharp range detector

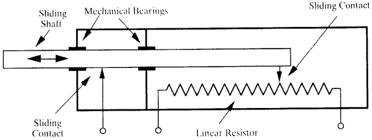


https://youtu.be/tStBLAiQaC8

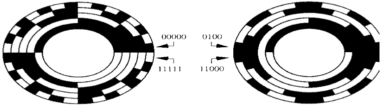
Position Sensors

- Rotary





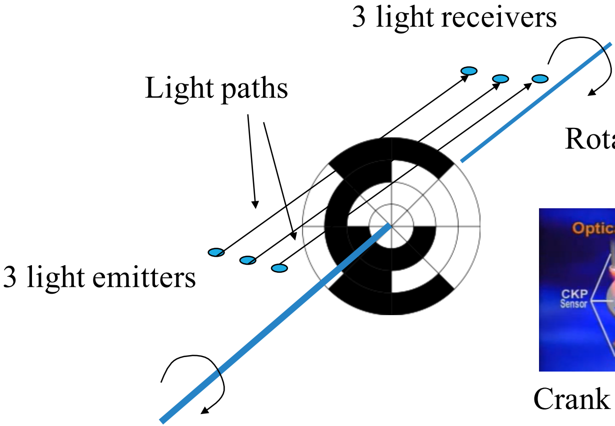
- Rotary Encoder

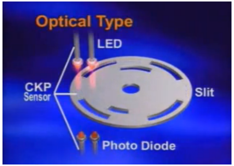


- Digital Linear Encoder

Optical Rotary Encoder

- wiki page
- `https://youtu.be/RuIislTGOwA`
- The light received (on or off) will tell the rotation angle)





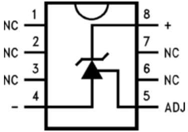
Crank shaft sensor

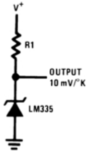
Magnetic rotary encoder

- Check the online info
- Non touch sensing

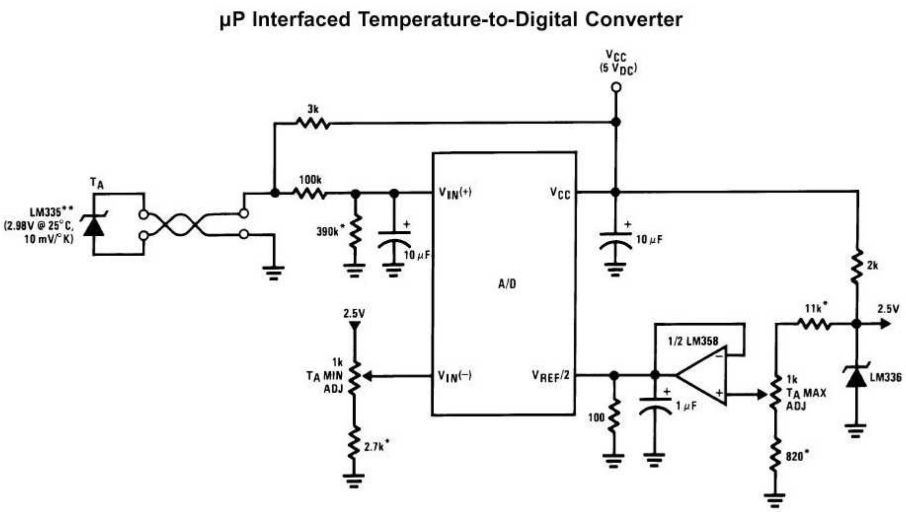
Temperature sensors

- Click the online document
- Directly calibrated in $^\circ$ 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$^\circ C$ over range
- Low cost





Application note



connecting to an ADC e.g. `ADC0820` or `ADC0801`

Humidity Sensor

- Check the online document
- Humidity range (RH) -> Capacitance
- `BCcomponents 2322 691 90001`: 10–90%RH Dc

QUICK REFERENCE DATA

PARAMETER	VALUE	UI
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/%
Frequency	1 to 1000	kHz
Maximum AC or DC voltage	15	V

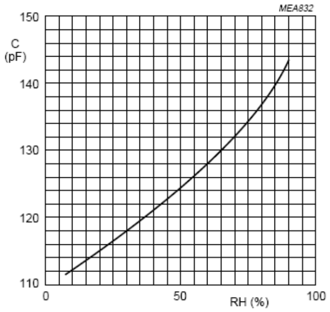
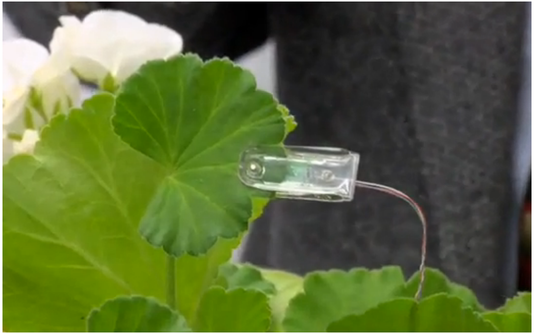


Fig.2 Typical capacitance as a function of relative humidity.

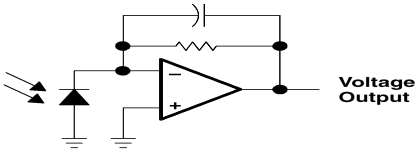
Leaf Sensor Alerts When Plants Are Thirsty



https://youtu.be/VM4X_fqPPco

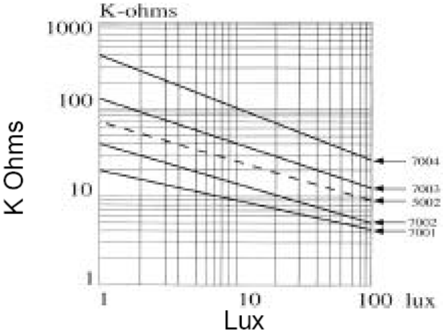
Light-to-voltage Optical Sensors

- Click the online document
- 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.



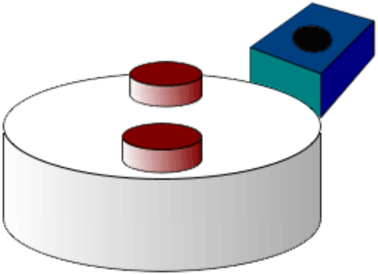
CdS Photoconductive Photocells

- Click the online document
- Cadmium Sulfoselenide (CdS)
- Light sensing using CdS



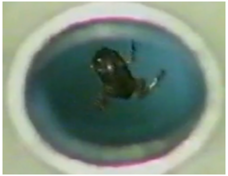
3-4. Hall effect Sensors

- 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

Magnetic levitation Train Model: https://youtu.be/TeS_U9qFg7Y

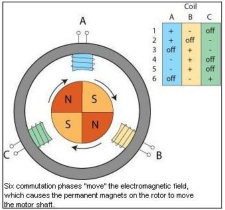


frog levitation https://youtu.be/A1vyB-O5i6E

https://youtu.be/XjjBqzilkIc

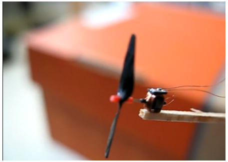
Hall effect sensors and brushless DC motors

Brushless DC motor

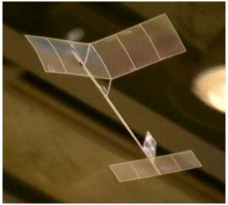


https://youtu.be/bCEiOnuODac

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



https://youtu.be/cm0h2Qf3upQ

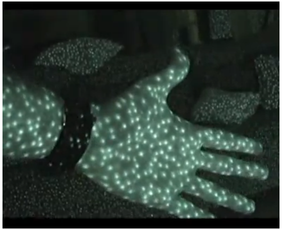


https://youtu.be/JmRkxZT4XhY

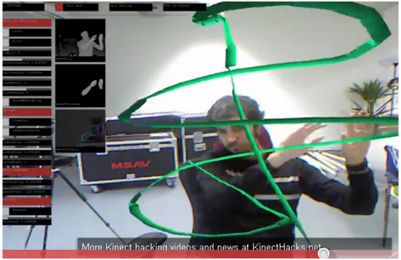
3-5. Kinect Sensors

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

https://youtu.be/p2qlHoxPioM



https://youtu.be/nvvQJxgykcU



https://youtu.be/Brpu30vjCa4

Summary

- Studied the characteristics of various sensors
- and their applications