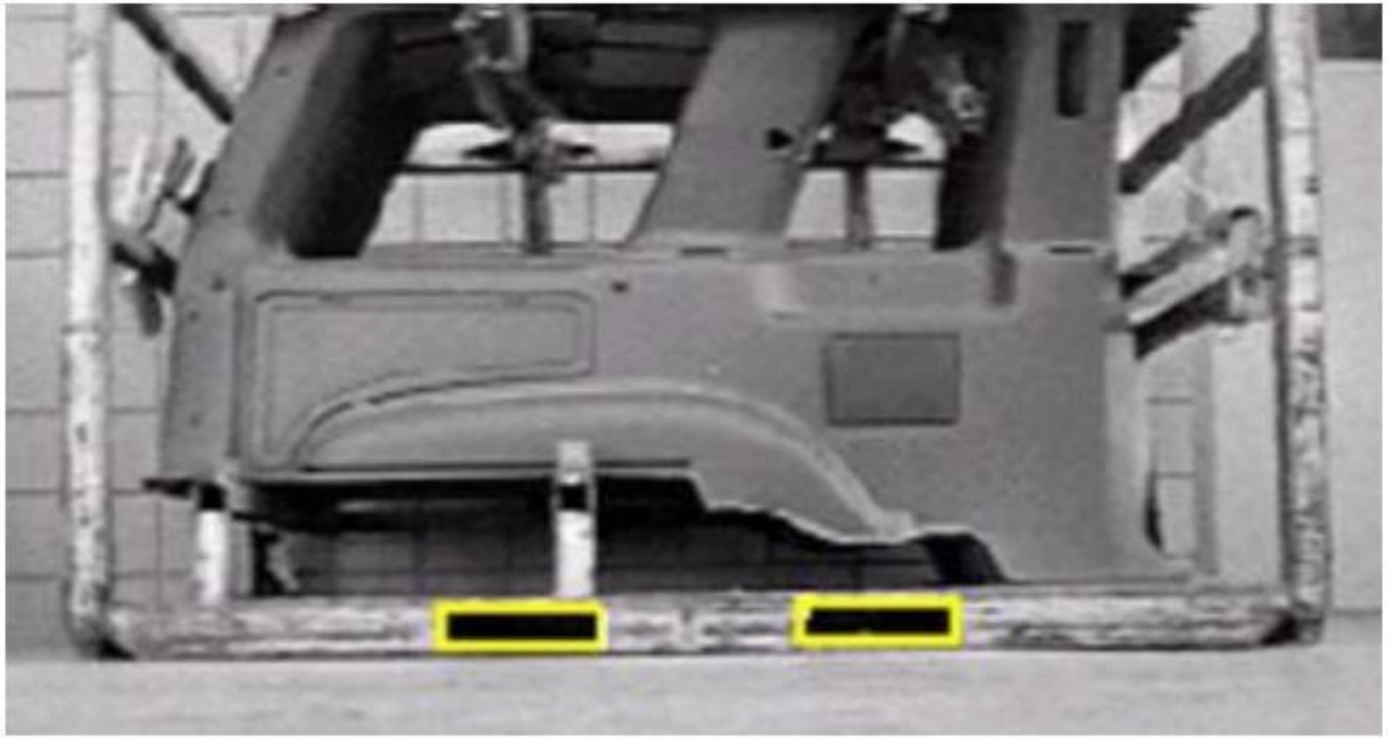
Pengantar Robotika

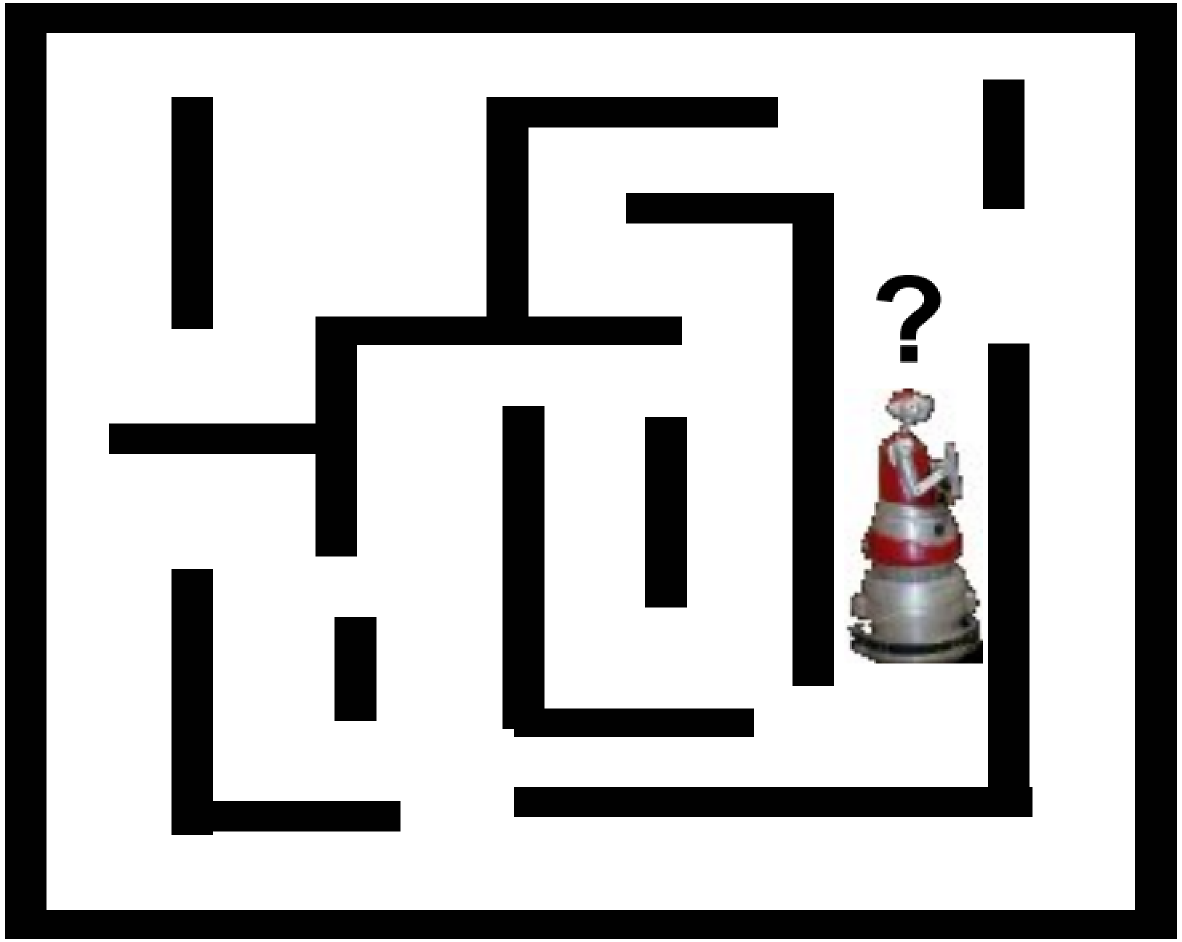
ROBOT SENSOR

Where are the forkholes?



Autonomous forklift for material handling

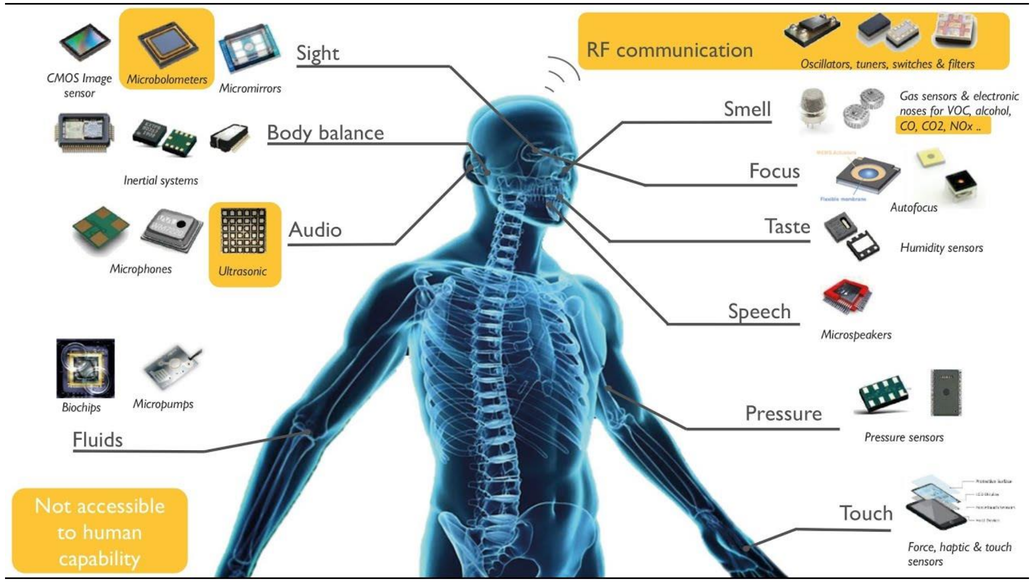
Where am I ?



Localization in the environment

Robot Sensors

- Sensor constitute robot's window to the environment.
- A robot needs sensing to be an active participant in the environment.
- Each sensor is based on a transduction principle, i.e. a conversion of energy from one form to another.
- Sensors measure a physical quantity, they do not provide state



Robot Sensors

- Sensors are devices for sensing and measuring geometric and physical properties of robots and the surrounding environment.
  - Position, orientation, velocity, acceleration
  - Distance, size
  - Force, moment
  - Temperature, luminance, weight
  - Etc.

Ultrasonic

Infra-red

Touch

Classification of sensors

- PROPRIOCEPTIVE ("sense of self", internal state).
  - Measures values internally to the system (robot), e.g. battery level, wheel position, joint angle, etc.
- EXTEROCEPTIVE (external state).
  - Observations of robot environment, objects in it

- ACTIVE (emits energy, e.g. radar) vs.
- PASSIVE (passively receives energy, e.g., camera).

Review

For the following picture, determine which measurement signal is internal and which is external according to the robot's point of view !

No	Fenomena yang dideteksi	Internal / Eksternal
1	Robot menghadap kemana ?	Internal
2	Robot miring atau tegak ?	Internal
3	Bola dimana ?	Eksternal
4	Ada lawan didepan atau tidak ?	Eksternal
5	Leher menunduk berapa derajat?	Internal
6	Permainan sedang berjalan atau tidak ? (WiFi)	Eksternal
7	Kaki kanan menginjak lantai atau tidak ?	Eksternal
8	Body robot bergoyang kemana ?	Internal
9	Sendi kaki overload atau tidak?	Internal
10	Seberapa jauh gawang dari robot ?	External
11	Dimana posisi robot relative terhadap lapangan ?	Eksternal
12	Robot jatuh kebelakang atau ke depan ?	Internal

General Classification of Sensors

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush encoders	PC	P
	Potentiometers	PC	P
	Synchros, resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacitive encoders	PC	A
Heading sensors (orientation of the robot in relation to a fixed reference frame)	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P

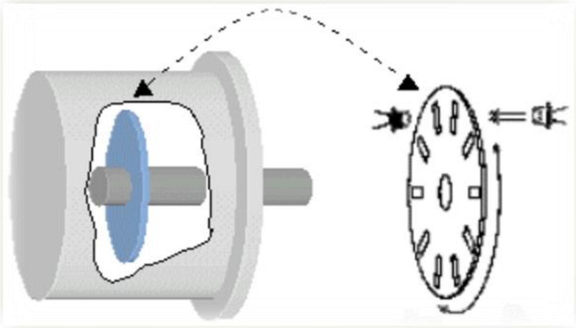
A, active; P, passive; P/A, passive/active; PC, proprioceptive; EC, exteroceptive.

General Classification of Sensors

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Ground-based beacons (localization in a fixed reference frame)	GPS Active optical or RF beacons Active ultrasonic beacons Reflective beacons	EC EC EC EC	A A A A
Active ranging (reflectivity, time-of-flight, and geometric triangulation)	Reflectivity sensors Ultrasonic sensor Laser rangefinder Optical triangulation (1D) Structured light (2D)	EC EC EC EC EC	A A A A A
Motion/speed sensors (speed relative to fixed or moving objects)	Doppler radar Doppler sound	EC EC	A A
Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)	CCD/CMOS camera(s) Visual ranging packages Object tracking packages	EC	P

Proprioceptive Sensors

- **Internal sensors: Obtain the information about the robot itself.**
  - **Position sensor, velocity sensor, acceleration sensors, motor torque sensor, etc.**



Optical Encoder

Acceleration Sensors

Velocity Sensor

Exteroceptive Sensors

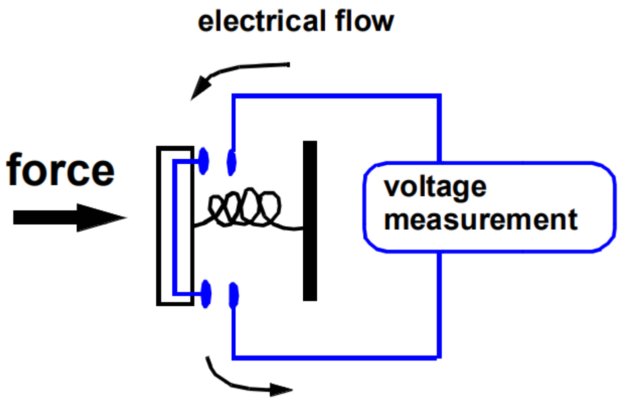
- External sensors: Obtain the information in the surrounding environment.
  - Cameras for viewing the environment
  - Range sensors: IR sensor, laser range finder, ultrasonic sensor, etc.
  - Contact and proximity sensors: Photodiode, IR detector, RFID, touch etc.
  - Force sensors: measuring the interaction forces with the environment,
  - etc

Sensor Lidar

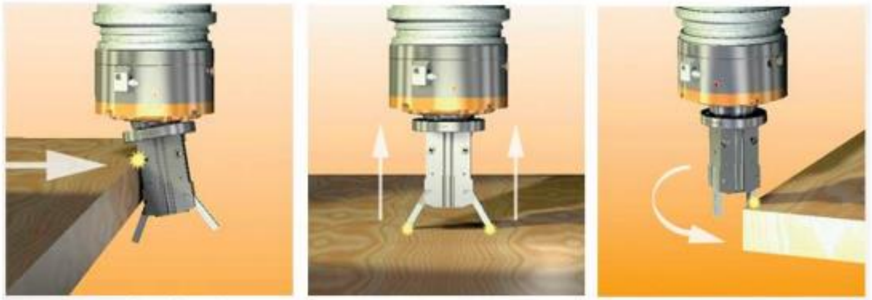
A Mobile Robot With External Sensors

A simple on/off touch sensor

- A simple switch
  - Very Simple
  - On-Of



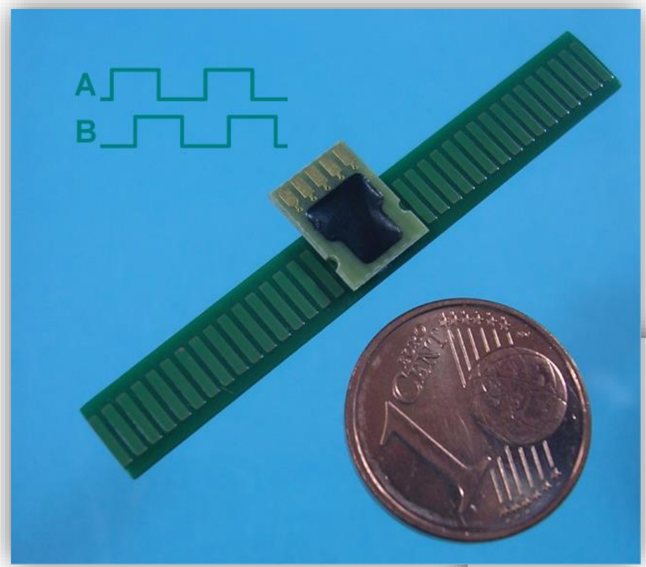
- Robotic collision sensor
  - 3-axis

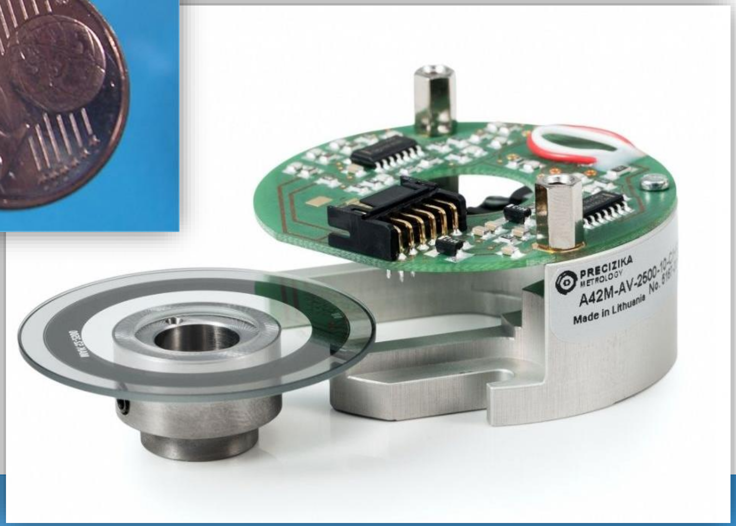


Angular Crash | Compressive Axial Crash | Torsional Crash

Position Measurement

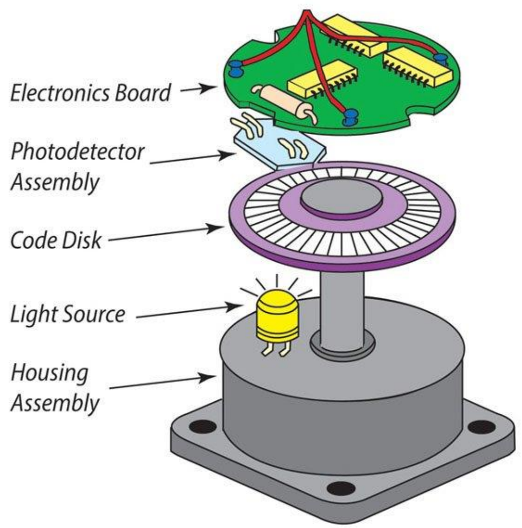
- Optical Encoder
- Magnetic Encoder

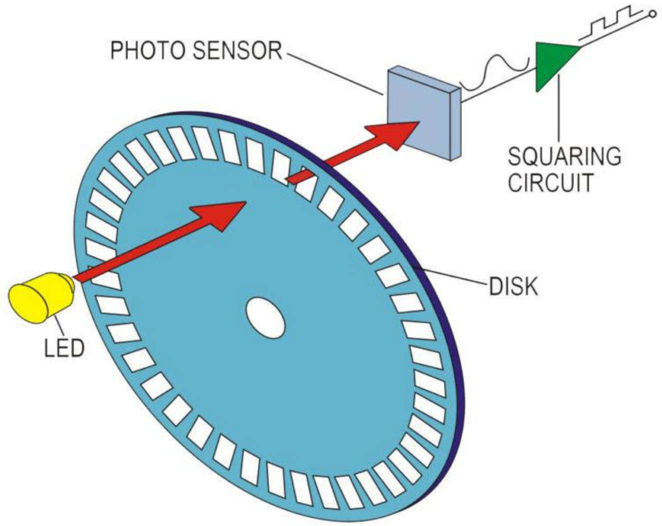




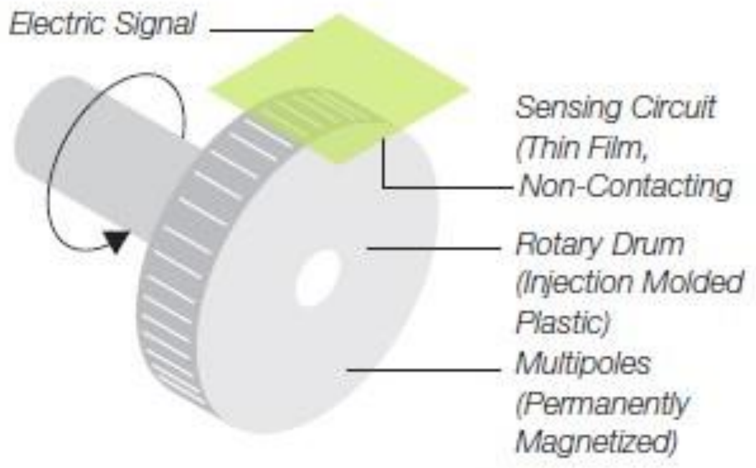
Optical Encoder

- An optical encoder is to measure the rotational angle of a motor shaft.
- It consists of a light beam, a light detector, and a rotating disc with a radial grating on its surface.
- The grating consists of black lines separated by clear spaces. The widths of the lines and spaces are the same.
  - Line: cut the beam → a low signal output
  - Space: allow the beam to pass → a high signal output
- A train of pulses is generated with the rotation of the disc. By counting the pulses, it is possible to know the rotational angle



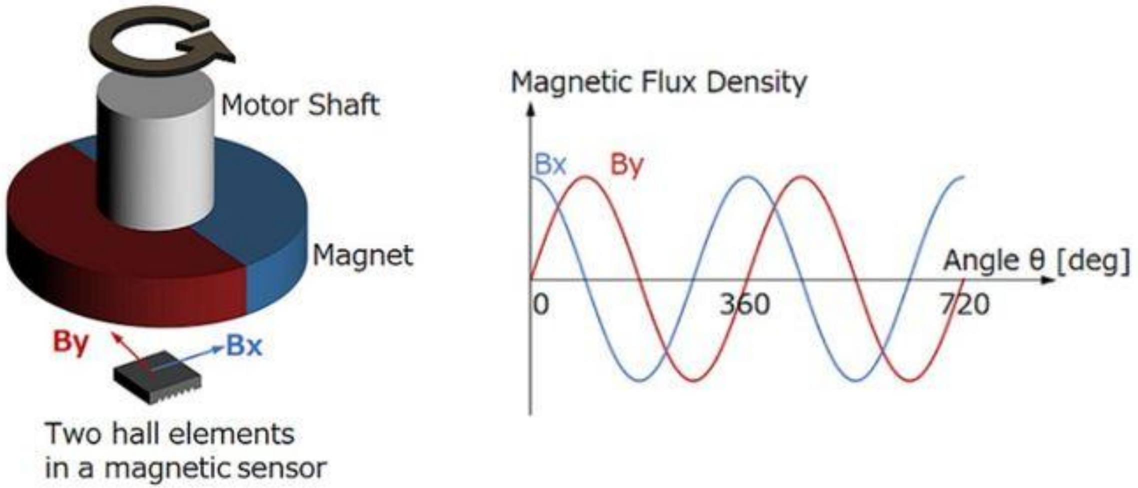


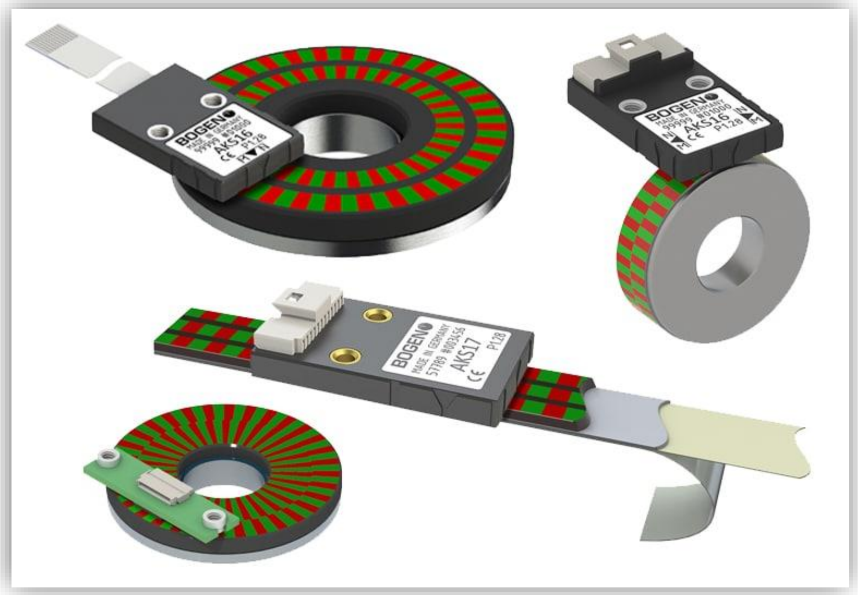
Magnetic Encoder



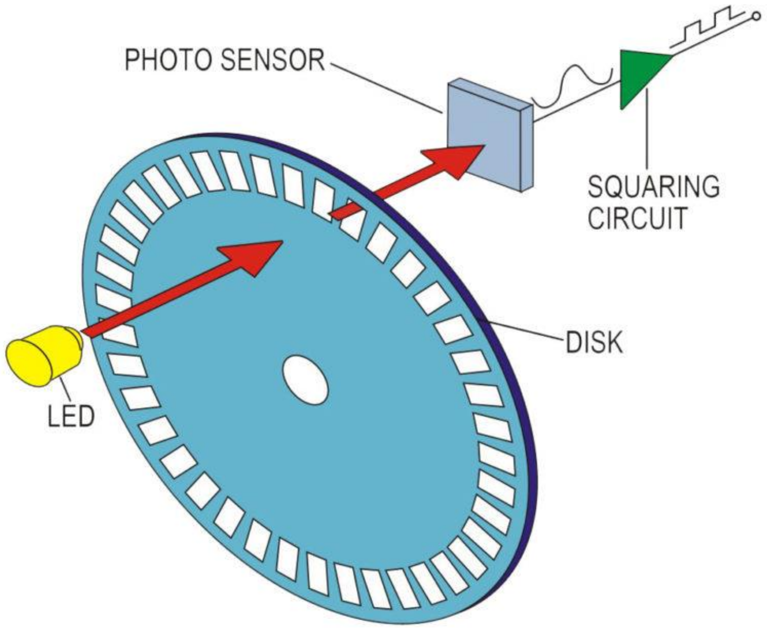
The magnetic encoder detects rotational position information as changes of the magnetic field, converts them into electrical signals, and outputs them. The simplest magnetic encoder consists of a permanent magnet and a magnetic sensor.

- Sensing Circuit
- A rotating wheel or ring
- A series of magnetic poles around the circumference of the wheel or ring

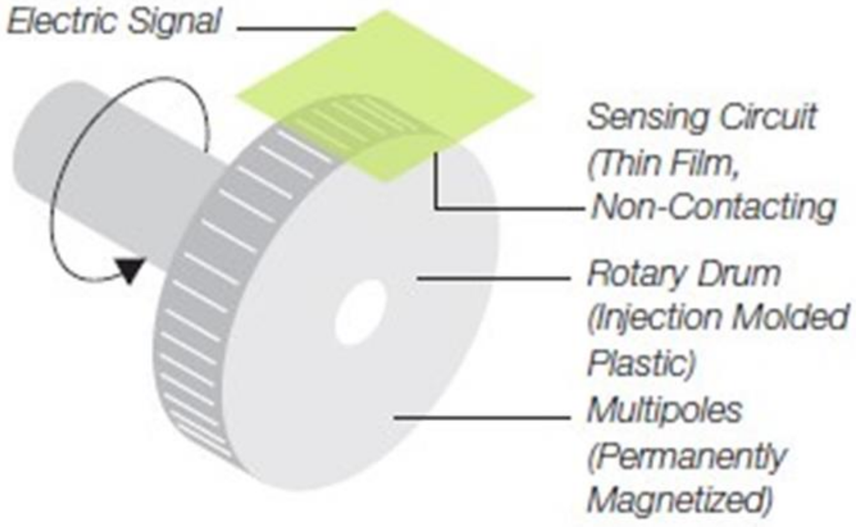




Rotary Encoder

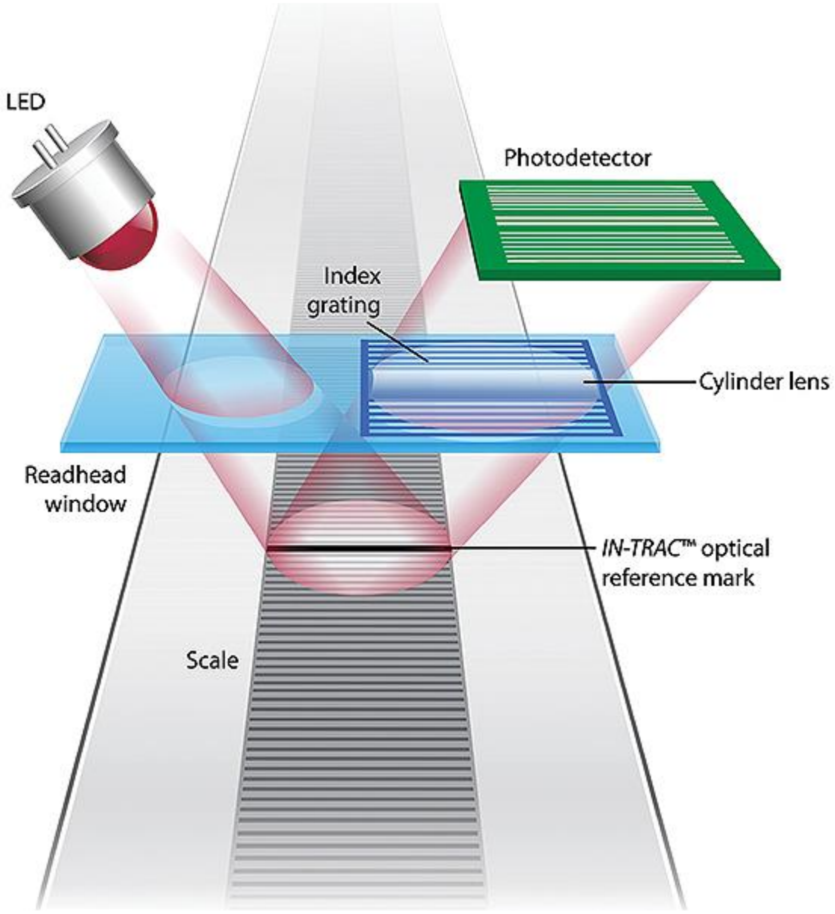


Optical Rotary Encoder

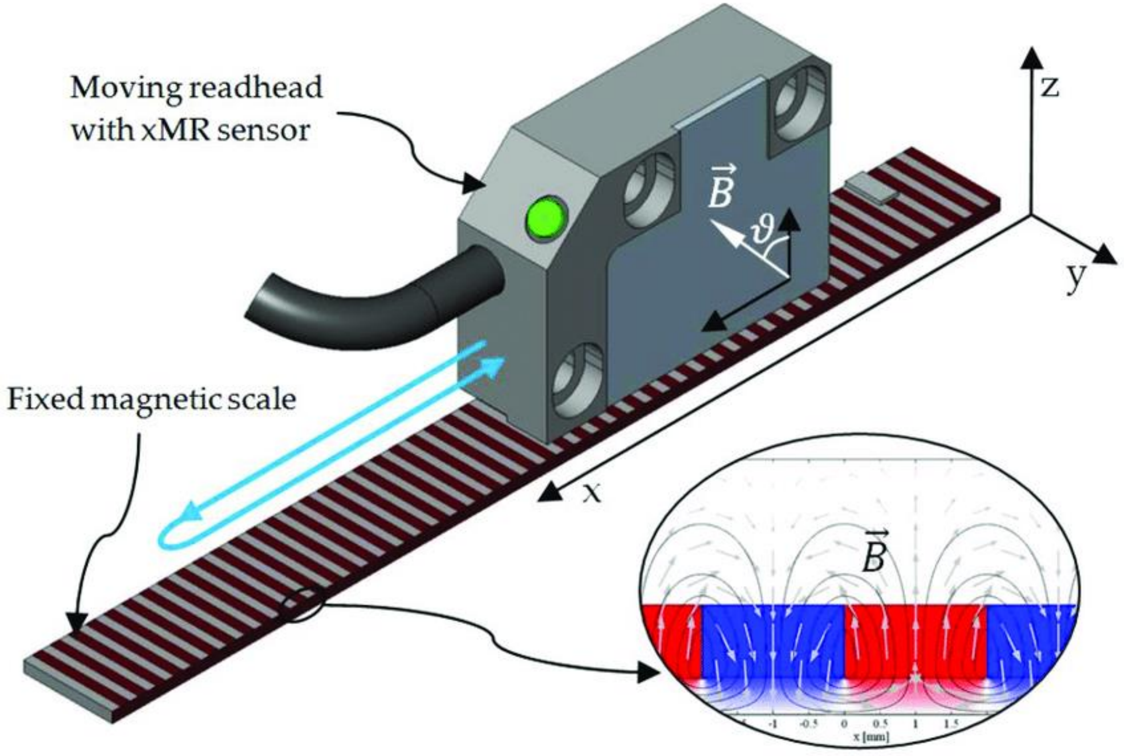


Magnetic Rotary Encoder

Linear Encoder



Optical Linear Encoder



Magnetic Linear Encoder

Resolution

- **Resolution of measurement**

$$s = \frac{360°}{number\ of\ lines(spaces)}$$

- **The smaller is the resolution, the better is the measurement**

How to increase the resolution

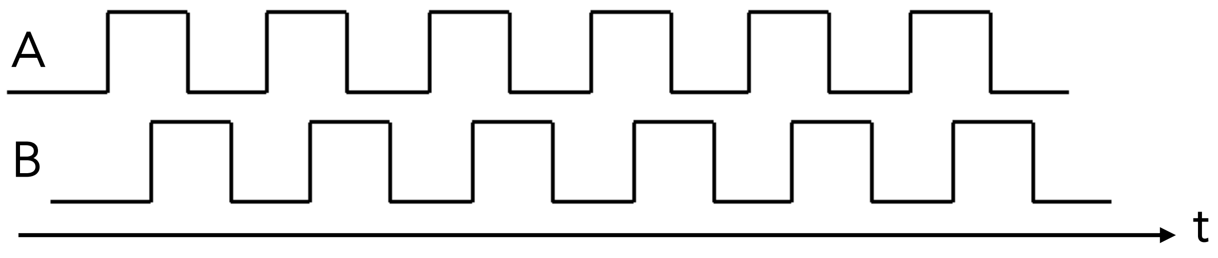
- To make the value of s smaller.
  - Increase the number of lines/spaces → the manufacturing cost will be increased
  - Evaluate the two trains of pulses. The evaluation means to take set operations, interpolation, etc.

Optical Encoder

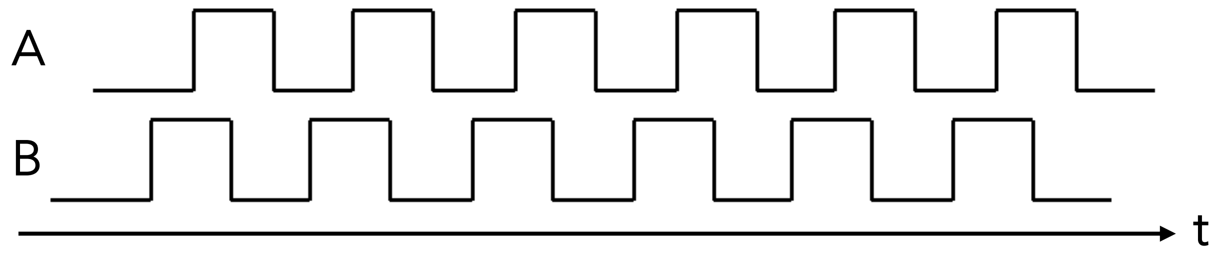
https://www.youtube.com/watch?v=nnk0DV5kgMk&t=2s

Optical Encoders

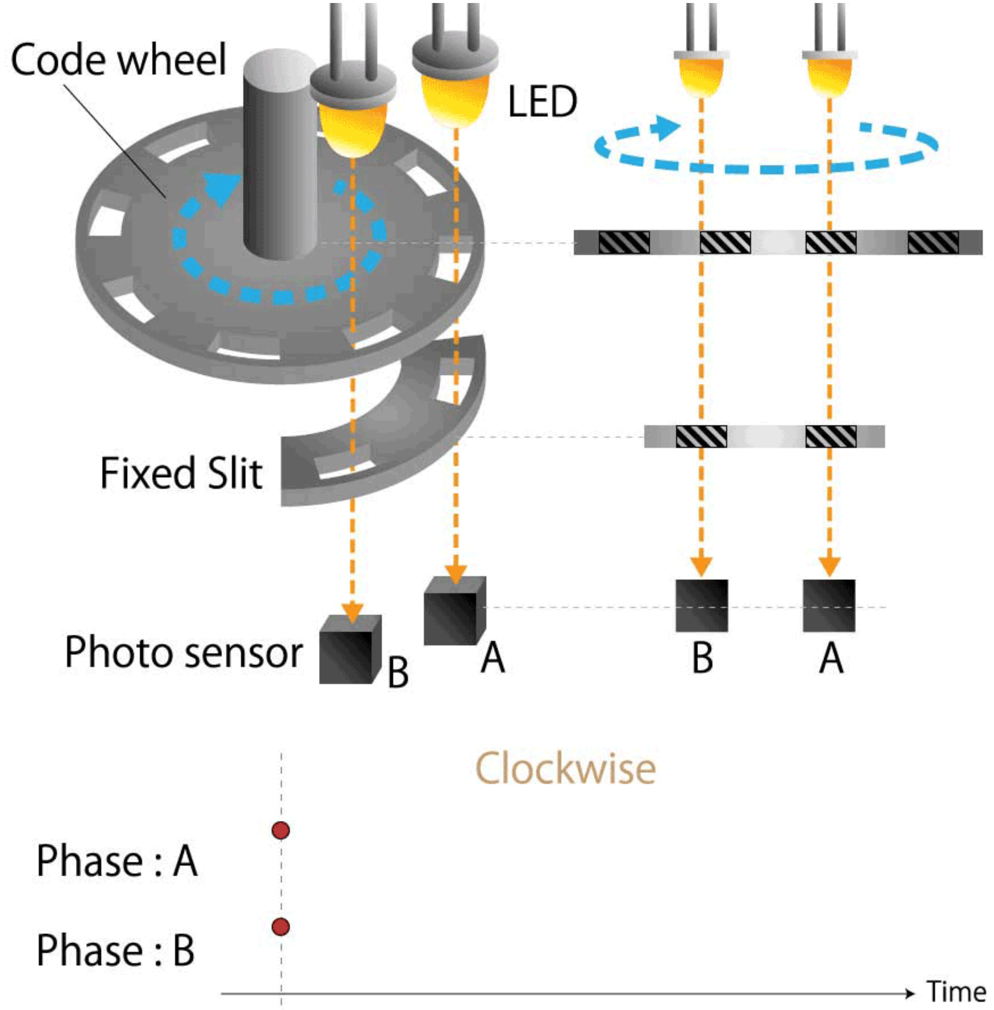
- The direction of rotation is determined by checking which phase of signals is leading.
- If Phase A signals are leading, the rotation is in the clockwise direction.

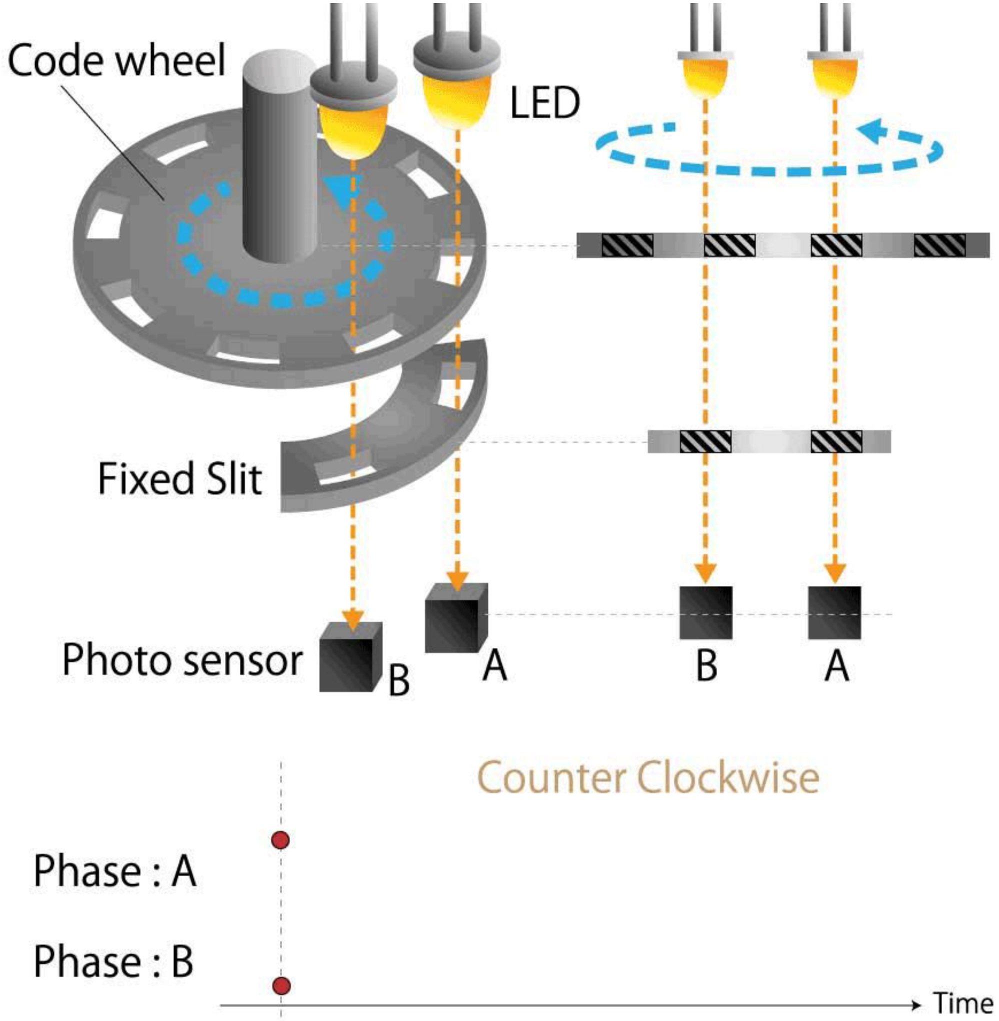


- If Phase B signals are leading, the rotation is the counterclockwise direction.

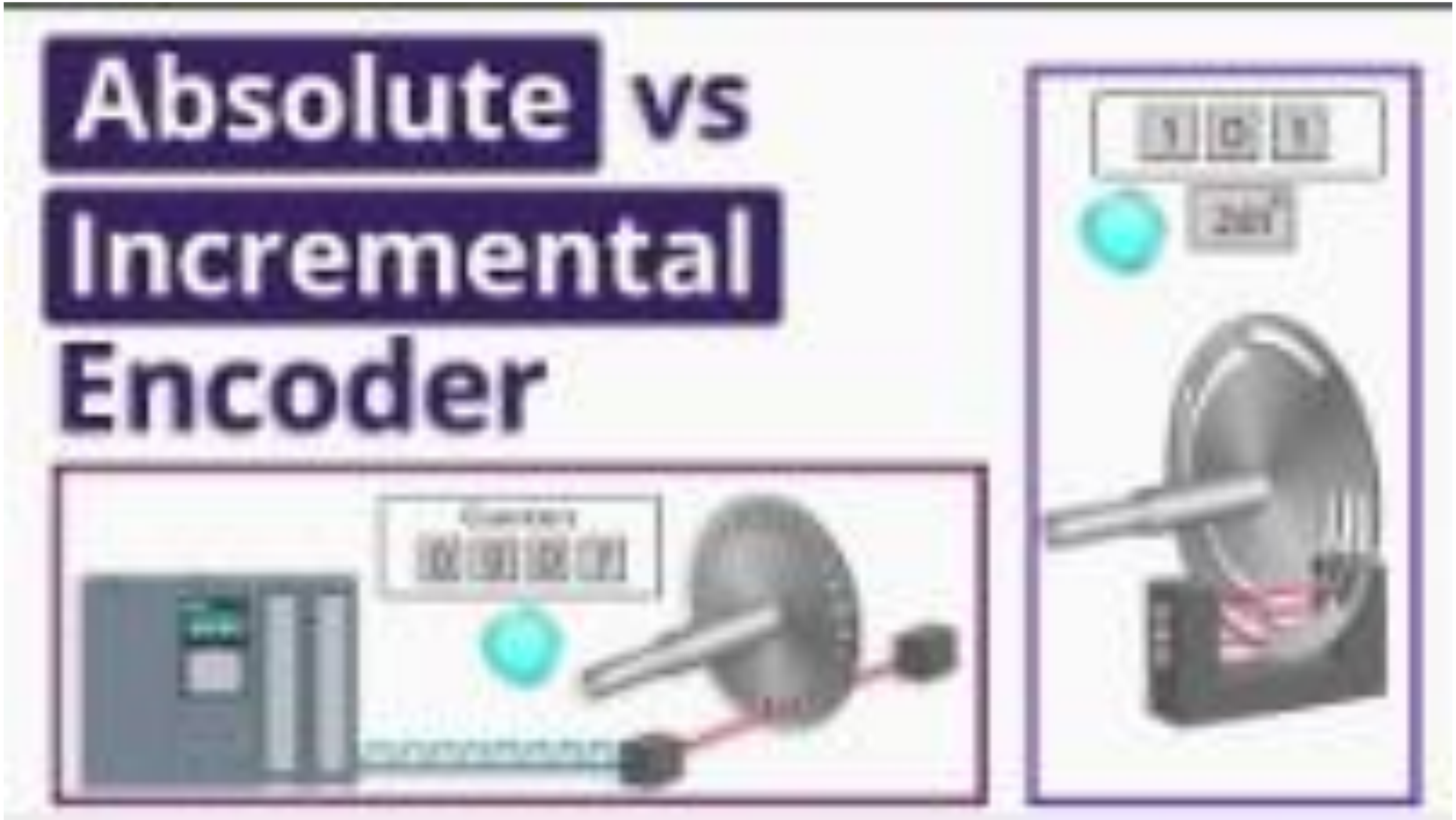


Rotation Direction





What is the Difference between Absolute and Incremental Encoders



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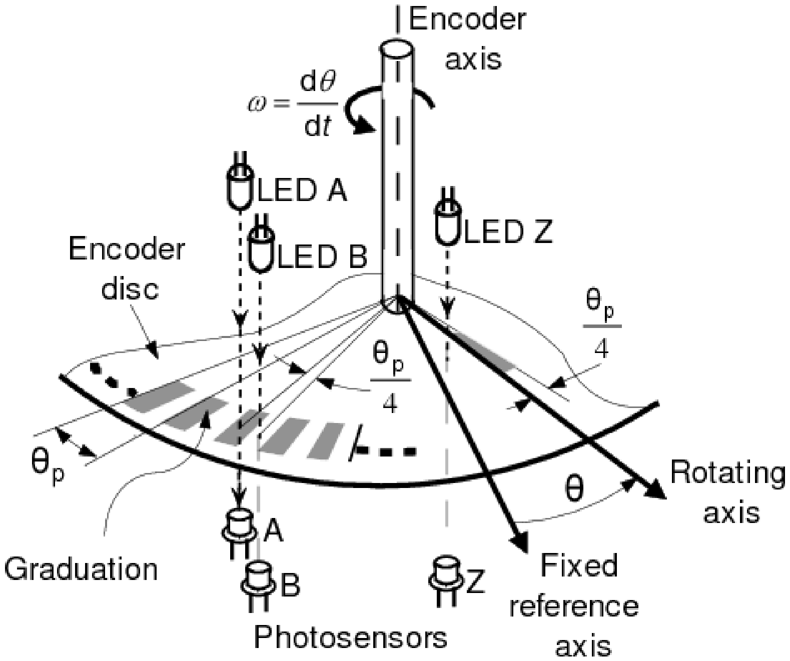
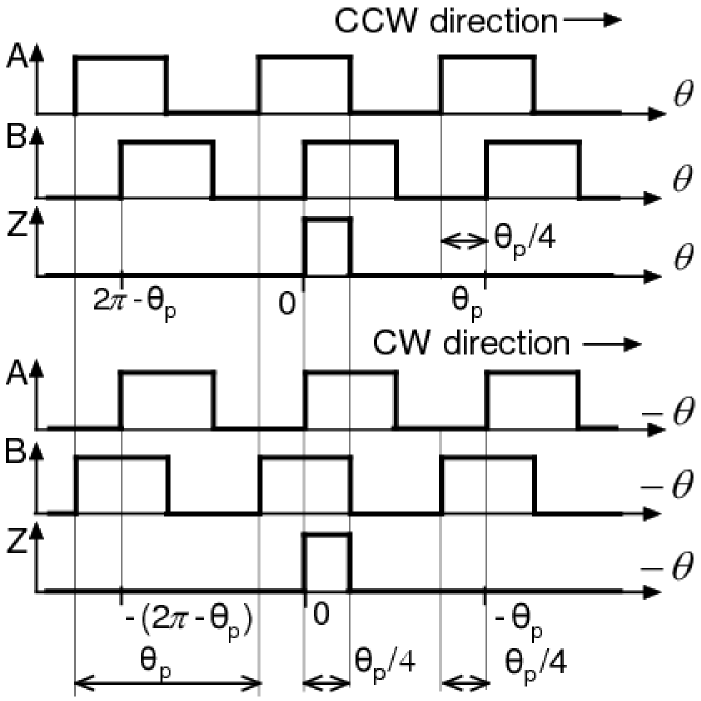
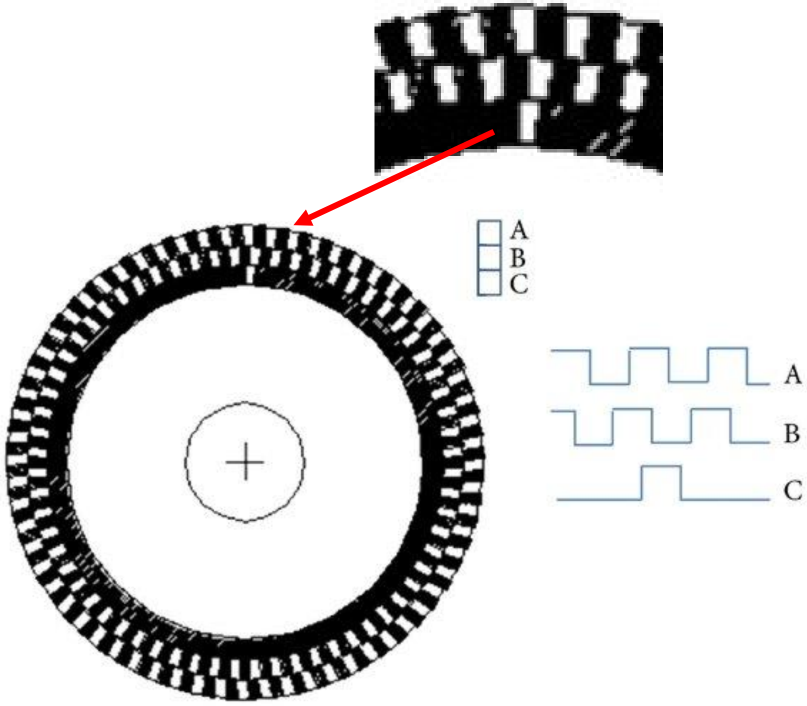
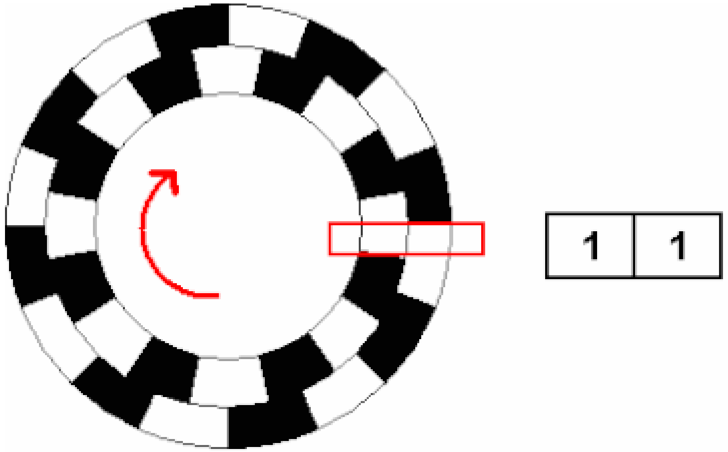
Incremental Encoder



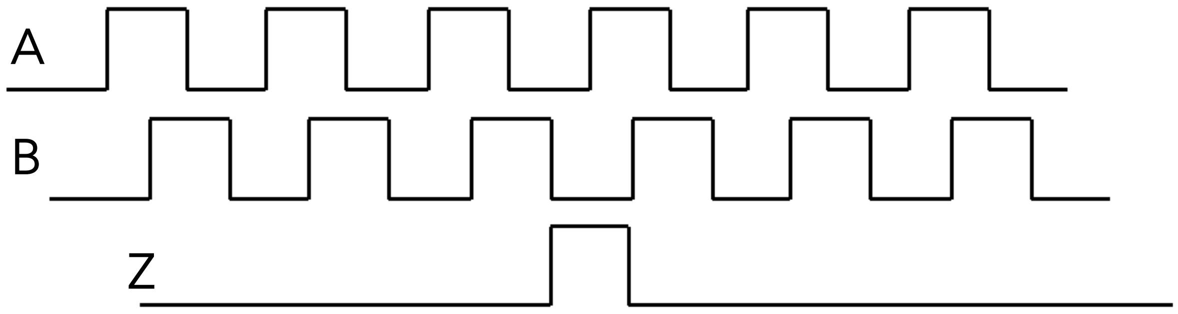






Incremental Encoder

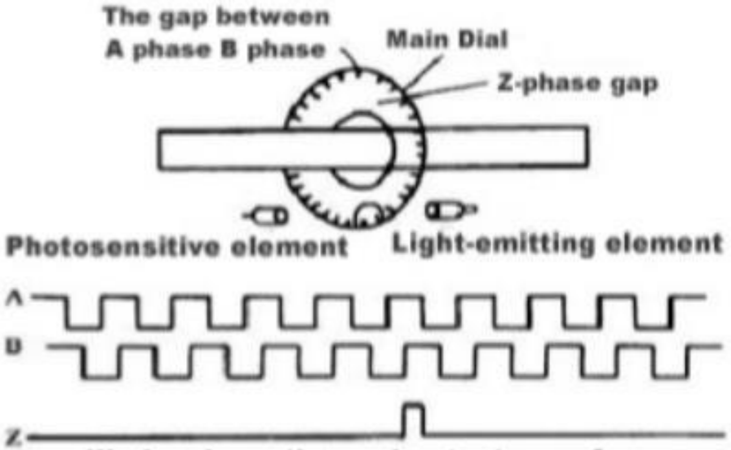
- Three phases of signals:
  - Phase A: A train of pulses
  - Phase B: A train of pulses.
  - Phase Z: A single pulse per turn.



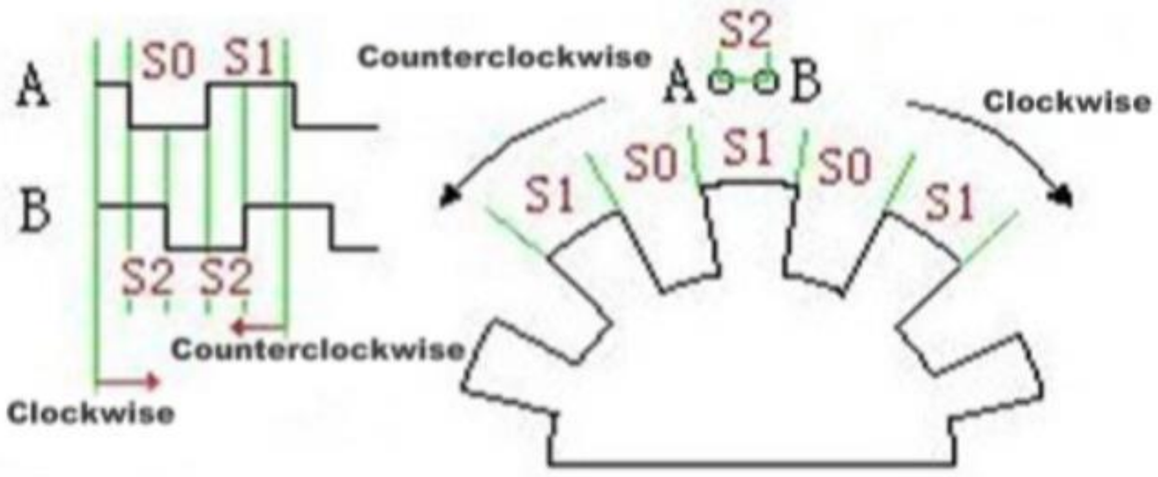
  - The phase difference between Phase A and Phase B is 90 degrees.
  - The Z-pulse is used as a reference angle (zero angle) so that the absolute angle can be detected.

Incremental Encoder

Clockwise movement	Counterclockwise movement
A B	A B
1 1	1 1
0 1	1 0
0 0	0 0
1 0	0 1

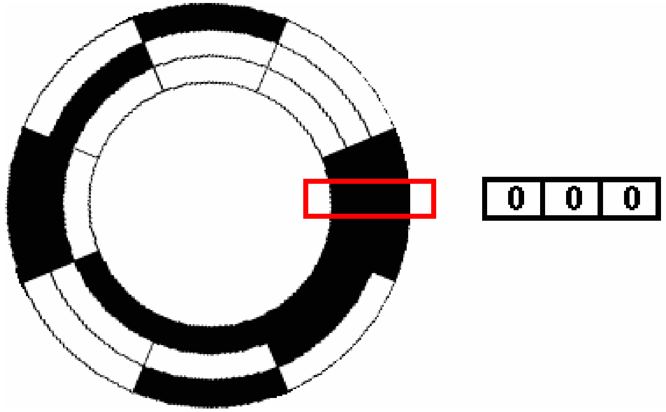


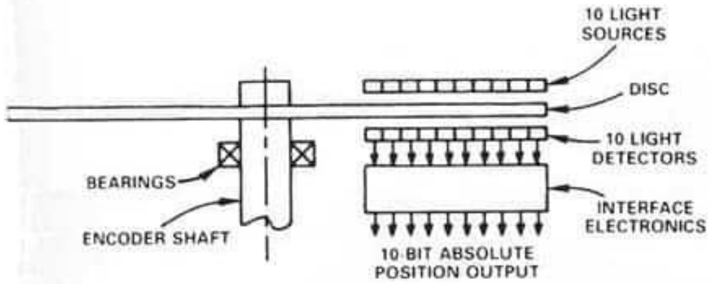
Work schematics and output waveforms



Absolute Encoder

Decimal	Binary	XOR	Gray	EQU
0	0000	0	0000	0
1	0001	1	0001	0
2	0010	1	0011	1
3	0011	0	0010	1
4	0100	1	0110	0
5	0101	0	0111	0
6	0110	0	0101	1
7	0111	1	0100	1
8	1000	1	1100	1
9	1001	0	1101	1
10	1010	0	1111	0
11	1011	1	1110	0
12	1100	0	1010	1
13	1101	1	1011	1
14	1110	1	1001	0
15	1111	0	1000	0

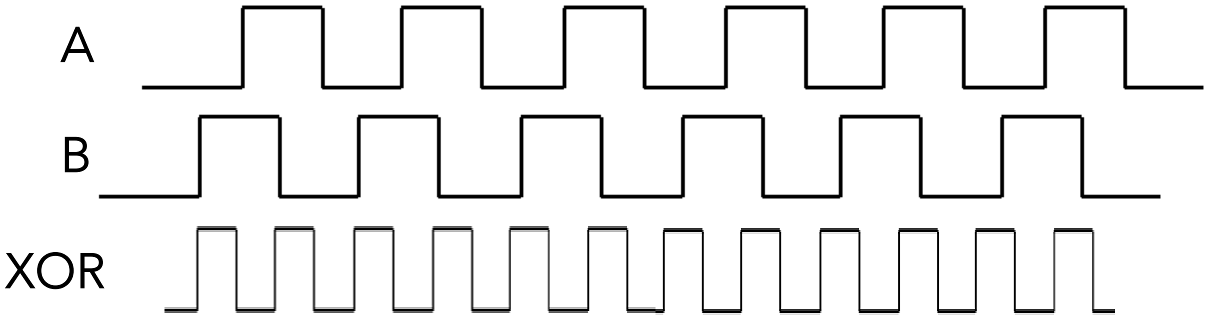




ABSOLUTE OPTICAL ENCODER INTERNAL CONSTRUCTION

Optical Encoders

- Set operations: Exclusive-or (XOR) operation (low output if the two pulses are the same, otherwise high)



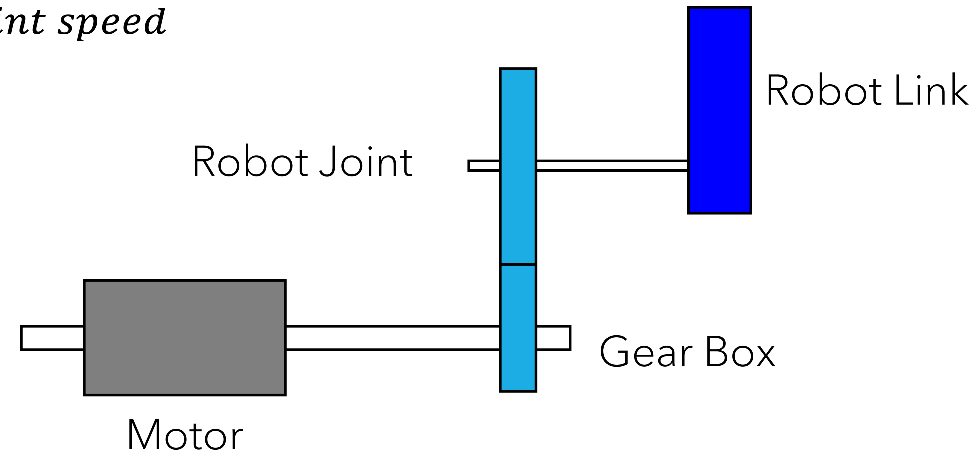
  - The frequency of the pulses train is doubled → the resolution will be doubled (the value becomes the half of the original one)
- By counting the raising and falling edges, the resolution can be increased 4 times.
- The resolution can be increased by interpolating the pluses, i.e. dividing a pulse into more pulses. Of course, this interpolation means approximation.

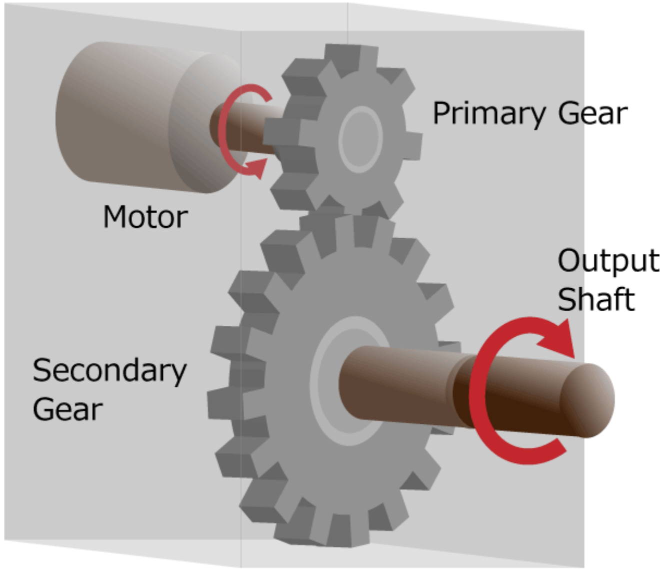
Optical Encoders

- In robotics, we are more interested in the measurement of joint angles instead of the angle of the motor shaft.
- By adding a reduction mechanism (gear box, etc), the measurement resolution of the joint angle will be increased n times, where n is the gear ratio (velocity ratio) of the reduction mechanism.
  - One turn of the joint corresponds to n turns of the motor shaft.

$$gear\ ratio(n) = \frac{radius\ of\ gear\ on\ joint}{radius\ of\ gear\ on\ motor}$$

$$= \frac{motor\ speed}{joint\ speed}$$





Geared Motor

Advantages and Disadvantages of an Encoder

Advantages

1. Highly reliable and accurate
2. Low-cost feedback
3. High resolution
4. Integrated electronics
5. Fuses optical and digital technology
6. Can be incorporated into existing applications
7. Compact size

Disadvantages

1. Subject to magnetic or radio interference (Magnetic Encoders)
2. Direct light source interference (Optical Encoders)
3. Susceptible to dirt, oil and dust contaminates

Other Position Sensor: Potentiometer

- Potentiometer = varying resistance

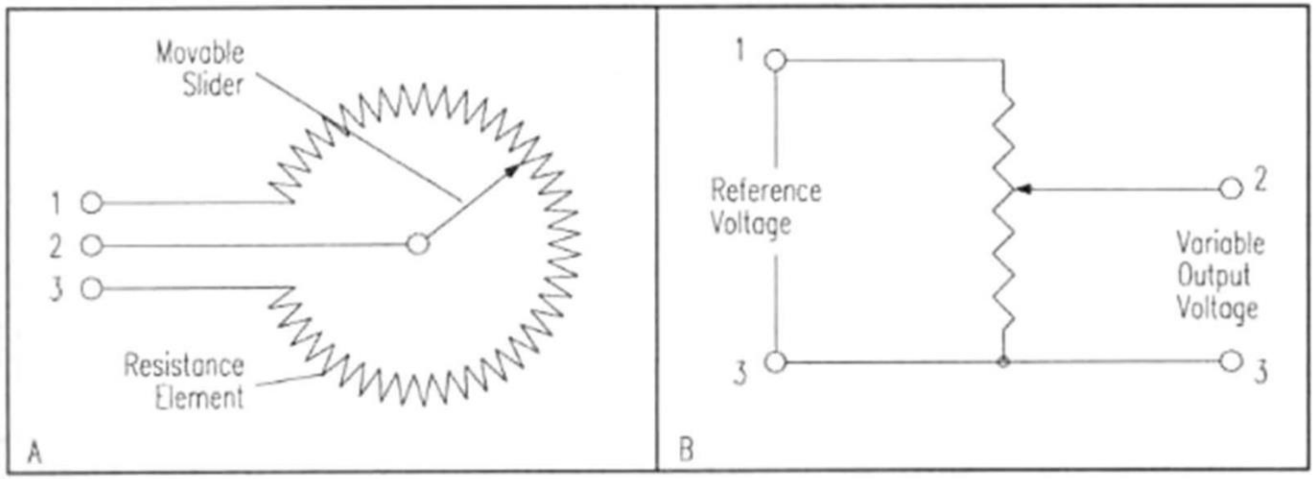


Figure 2-1. For a linear-taper pot, the output voltage V_o is directly related to the ratio of actual to full scale displacement.

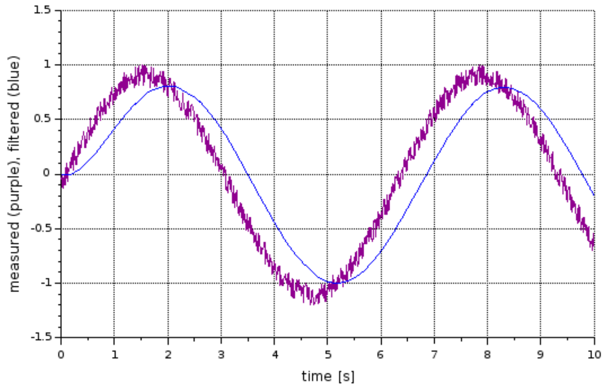
- Problems:
  - Frictions
  - Noisy
  - Nonlinearity
  - etc.

Velocity Measurement

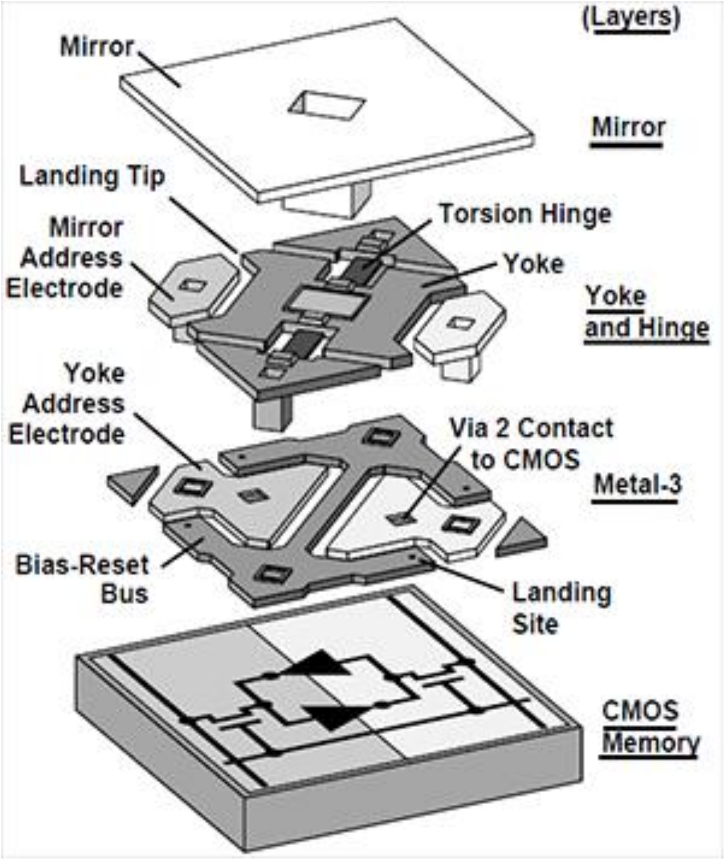
- Differentiate position: Use position sensors

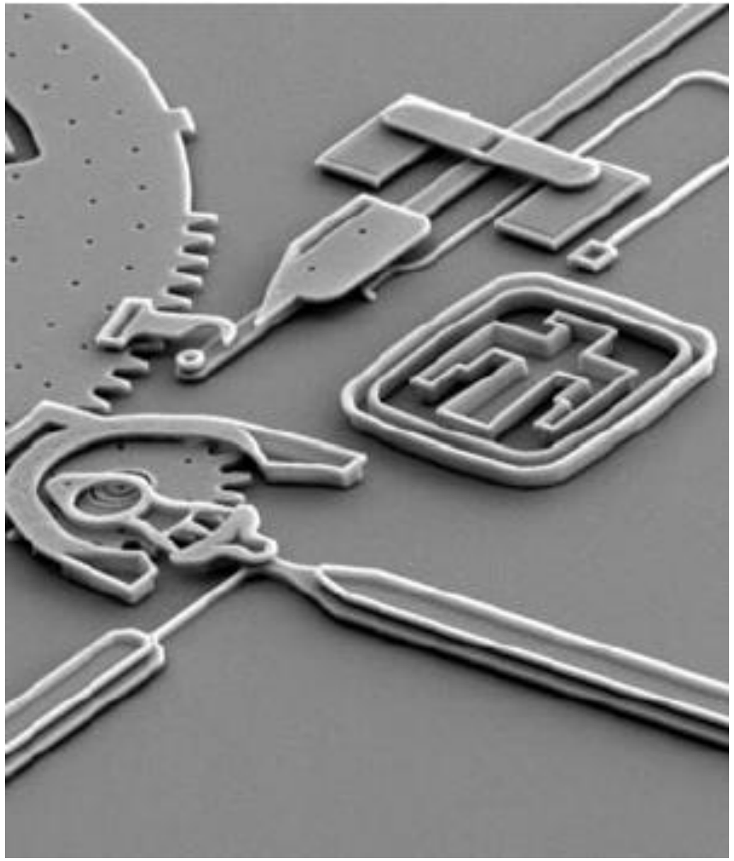
$$V = \frac{\Delta p}{\Delta t}$$

- Advantages : Simple, without using additional sensors
- Disadvantages: noisy signals
- Use low-pass filters to improve the accuracy, i.e. look at a few points before the current time, etc.



MEMS (Micro-Electro-Mechanical-System)



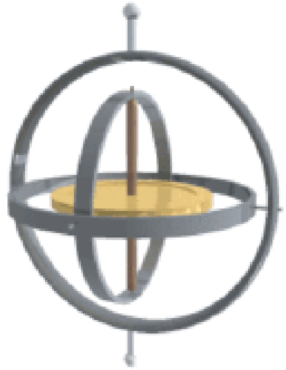


Suatu perangkat yang mengintegrasikan sensor, aktuator dan rangkaian elektronik dalam suatu substrate silicon melalui proses teknologi micro-fabrikasi, teknologi micro-manufacture untuk membuat perangkat microscopis

Inertial Sensors

Gyroscopes

- Heading sensors, that keep the orientation to a fixed frame
- Absolute measure for the heading of a mobile system

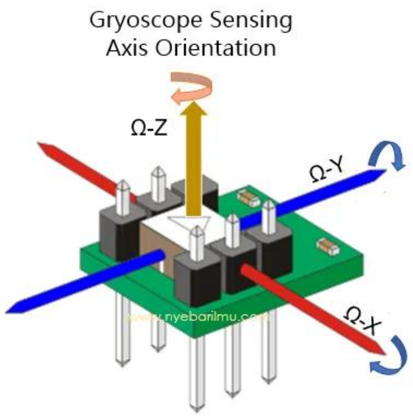


Accelerometers

- Measure accelerations with respect to an inertial frame

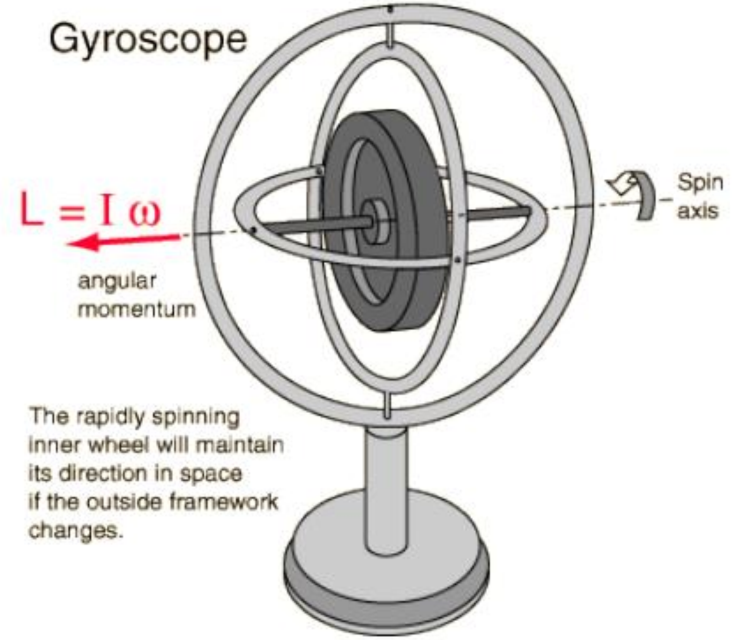
Gyroscope

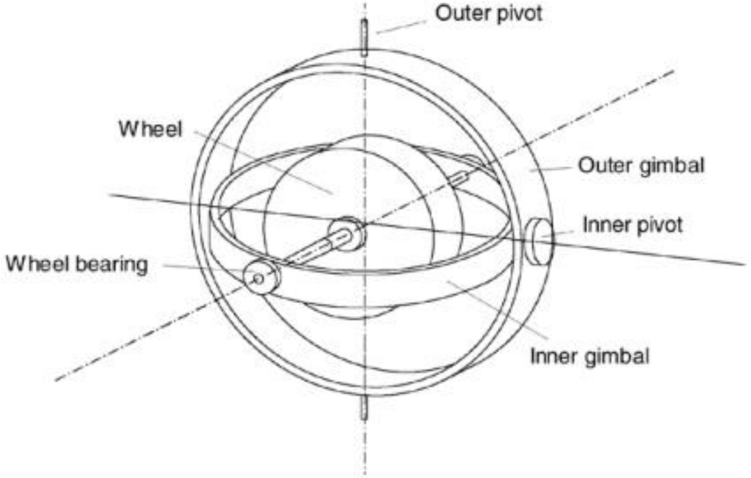
- Heading sensors, that keep the orientation to a fixed frame
- Gyroscopes are used in aeroplanes, segways
- Two gyroscope principles:
  - Mechanical (flywheel)
  - Electrical



Mechanical gyroscope

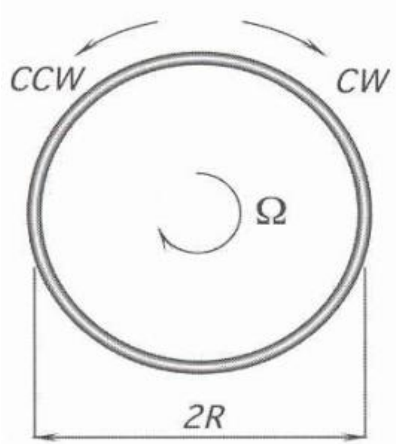
- A torque is applied to the frame of the gyro around the input axis
- The output axis will rotate as shown in a motion called precession
- This precession now becomes a measure of the applied torque and can be used as an output to, for example, correct the direction of an airplane or the position of a satellite antenna

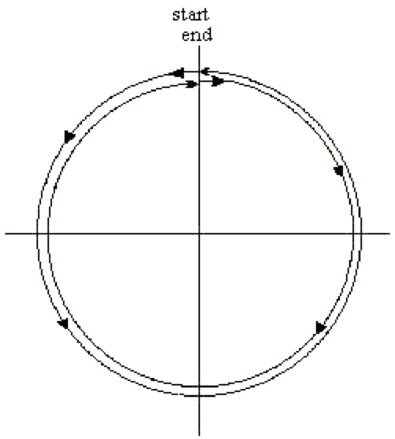


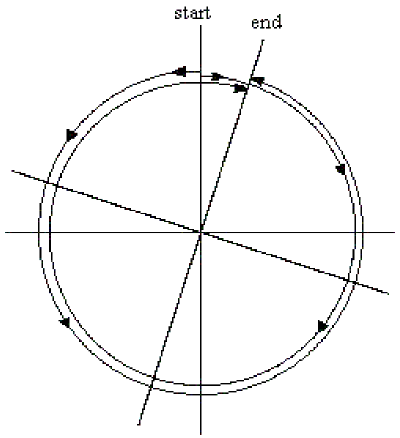


Optical gyroscope

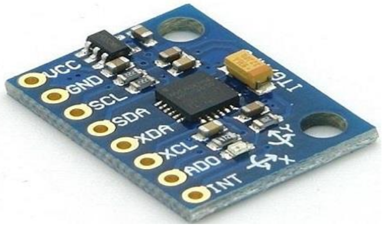
- First commercial use started only in the early 1980s when they where first installed in aero planes.
- Heading sensors using two monochromic light (or laser) beams from the same source.
- One is traveling in a fiber clockwise, the other counterclockwise around a cylinder.
- Laser beam traveling in direction of rotation has a slightly shorter path -> shows a higher frequency (Sagnac Effect)
- Difference in frequency Δf of the two beams is proportional to the angular velocity.



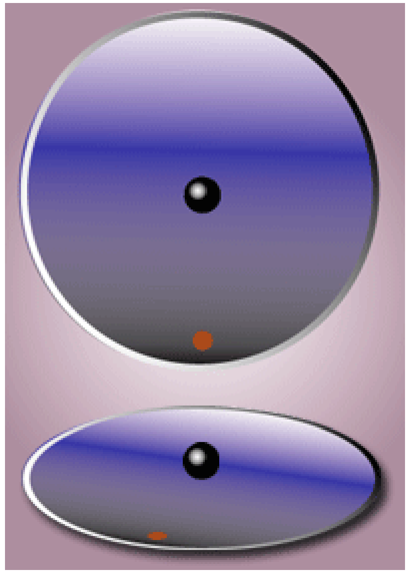


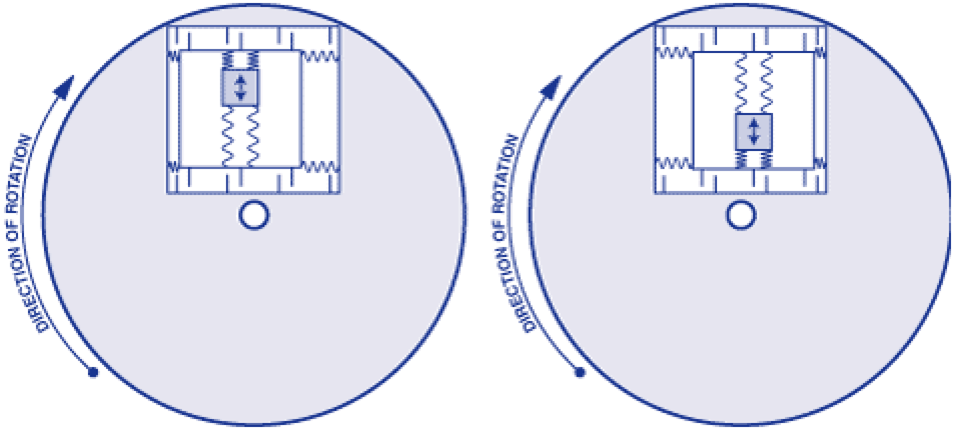


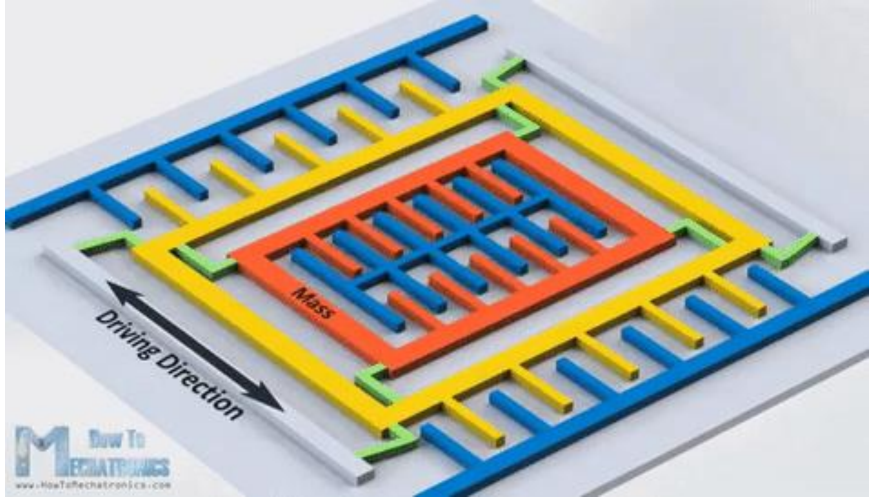
Electronic gyroscope



- MEMS (Micro-machined Electro-Mechanical Systems)
- Easily available commercially, affordable, and very small in size
- Based on Coriolis force
- The Coriolis force is detected by capacitive sense fingers that are along the mass housing and the rigid structure







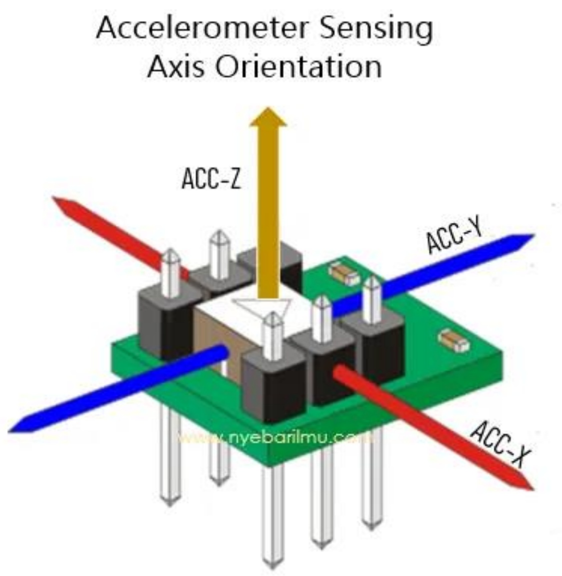
Applications of Gyroscopes

Can you give examples of applications of gyroscopes ?

- A bicycle
- An advanced navigation system on the space shuttle
- A typical airplane uses about a dozen gyroscopes in Everything from its compass to its autopilot.
- The Russian Mir space station used 11 gyroscopes to keep its orientation to the sun
- the Hubble Space Telescope has a batch of navigational gyros as well

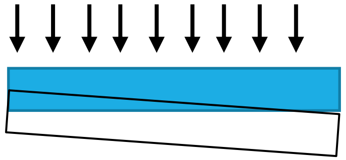
Acceleration Measurement

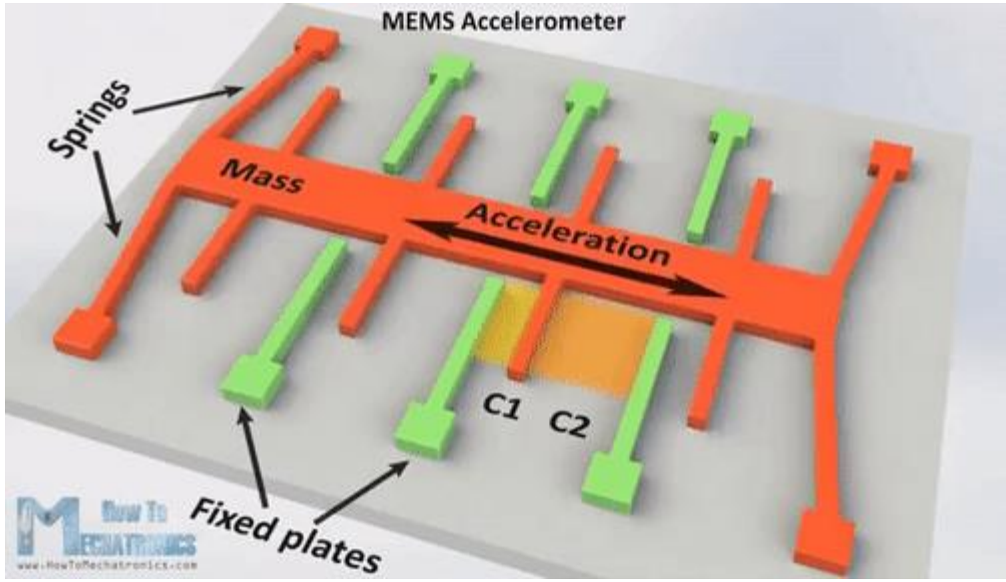
- Differentiation of the velocity signals -> noisy results
- This force may change
  - The tension of a string
  - The deflection of a beam
  - The vibrating frequency of a mass

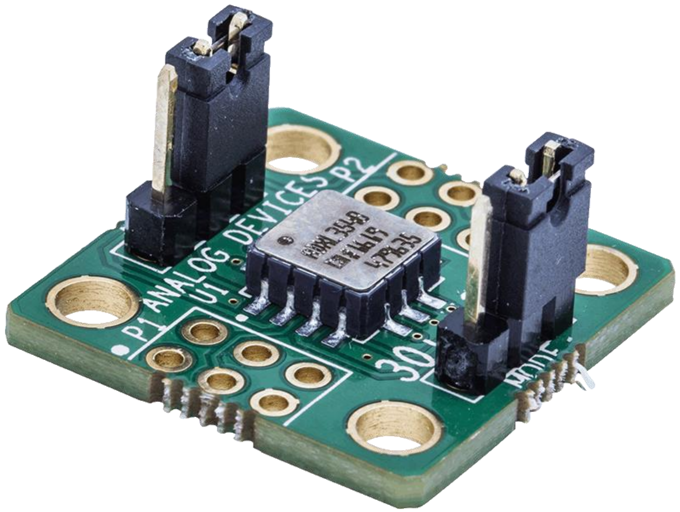


MEMS Accelerometer

- MEMs accelerometer: Measurement of bending of a MEMs structure under inertia forces.
  - Gravity force gives output
  - Low measurement accuracy
  - Drifting







Applications of Accelerometer

Can you give examples of applications of accelerometer ?

- To detect and monitor vibrations in rotating machinery.
- To display images in an upright position on screens of digital cameras.
- For flight stabilization in drones.
- These are also used for building and structural monitoring to measure the motion and vibration of the structure when exposed to dynamic loads.
- Remote sensing devices also use accelerometers to monitor active volcanoes.
- Fall detection on robot ICHIRO

Force Sensors

- Forces can be measured by measuring the deflection of an elastic element

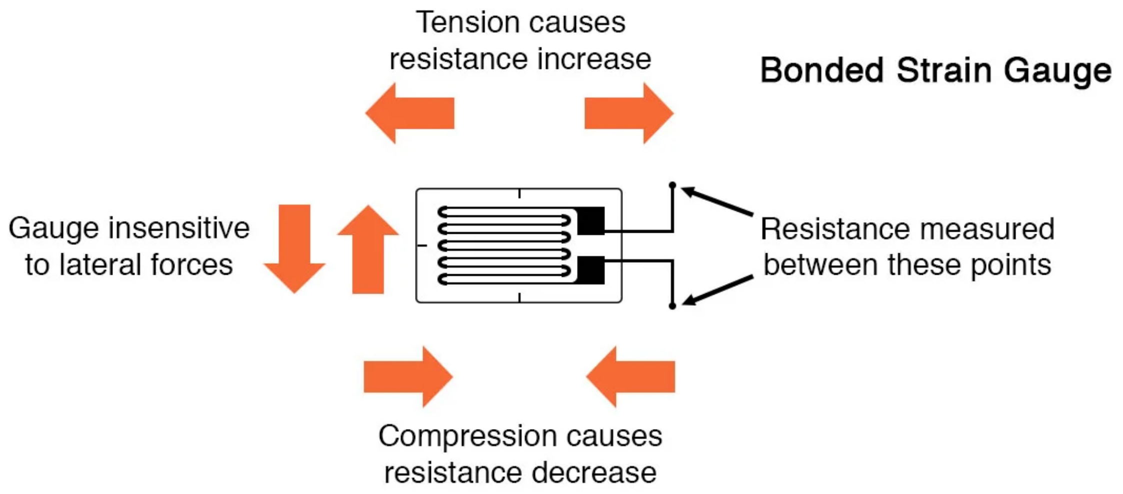
$$\varepsilon = \frac{\Delta l}{l} = strain$$

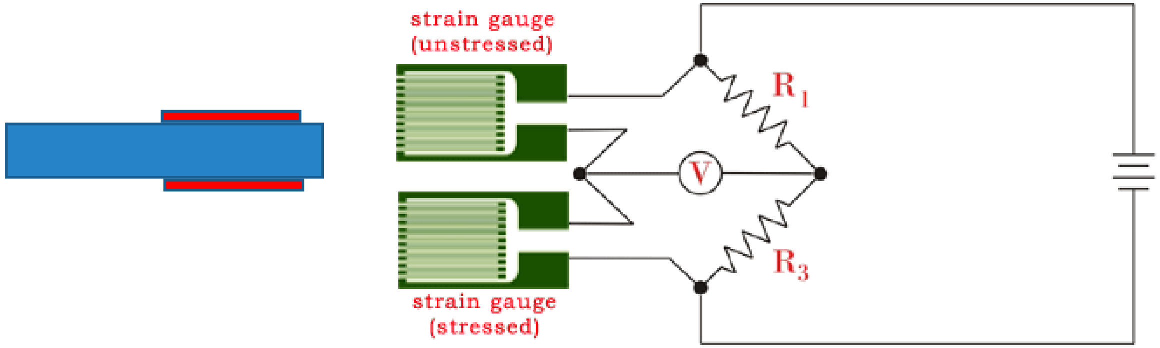
- Strain gauges: Most common sensing elements of force. It converts the deformation to the change of its resistance.

- Gauge resistance varies from 30 to 3K, corresponding to deformation from 30 μm to 100 μm.

Strain Gauge

- Sensitive to that small changes occur in the geometry of an object
- change in resistance normally has very small value
  - Solution : long thin metallic strip arrange in a zigzag pattern
- Whenever temperature changes, the resistance will change
  - Solution : quarter bridge strain gauge circuit
  - Two gauges to cancel the drift



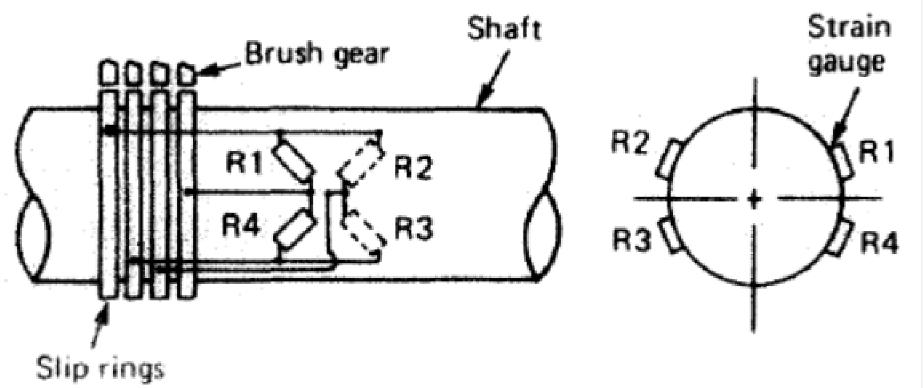


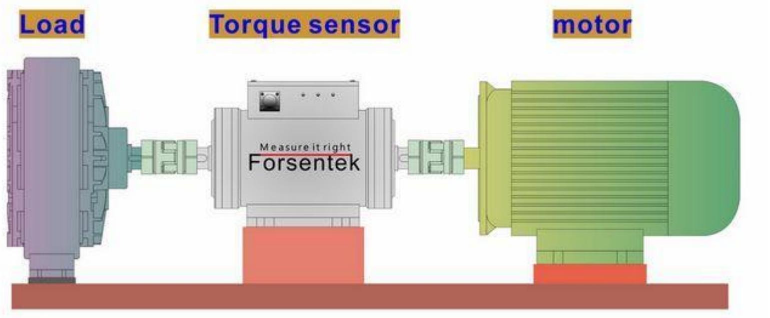
$$V_out = \left(\frac{R_2}{R_1+R_2} - \frac{R4}{R_3+R_4}\right) V_in$$

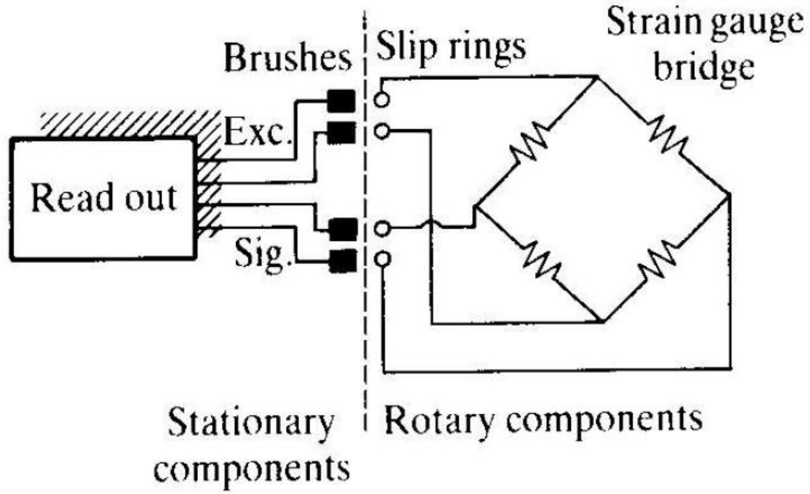
Quarter-bridge strain gauge circuit
with temperature compensation

Torque Sensor

- Shaft torque is measured with strain gauges mounted on a shaft with specially designed cross-section







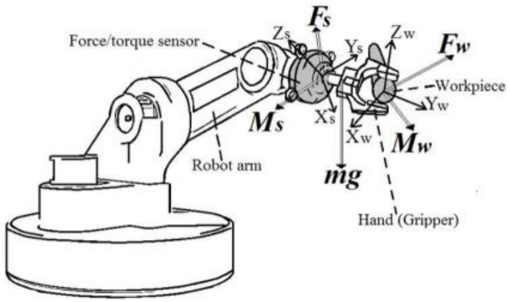
Applications of Force Sensor

Can you give examples of applications of Force Sensor ?

- Aerospace : measure stresses along load paths for wing deflection or deformation in an aeroplane
- Cable Bridges : measure the strain on its cables.
- Rail Monitoring : measure axial tension or compression with no impact on the rails
- Robotics : measure force and torque sensor on his arm

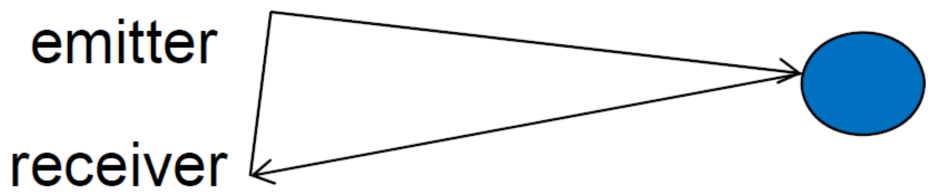
Force/torque sensors

- 3-axis force sensor
- 3-axis torque sensor

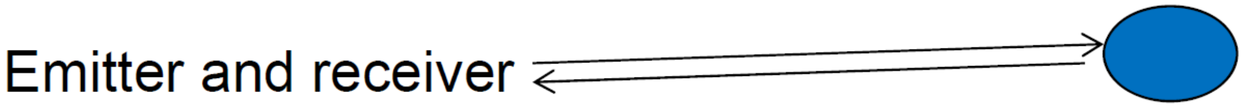


Range Sensors

- To measure the distance from the sensor to a nearby object
- Working principles :
  - Triangulation: Use the triangle formed by the traveling path of the signal to calculate the distance



  - Time-of-flight: Use the time of flight of the signals to measure the distance



IR Range Sensors

- Principle of operation: triangulation
  - IR emitter + focusing lens + position-sensitive detector

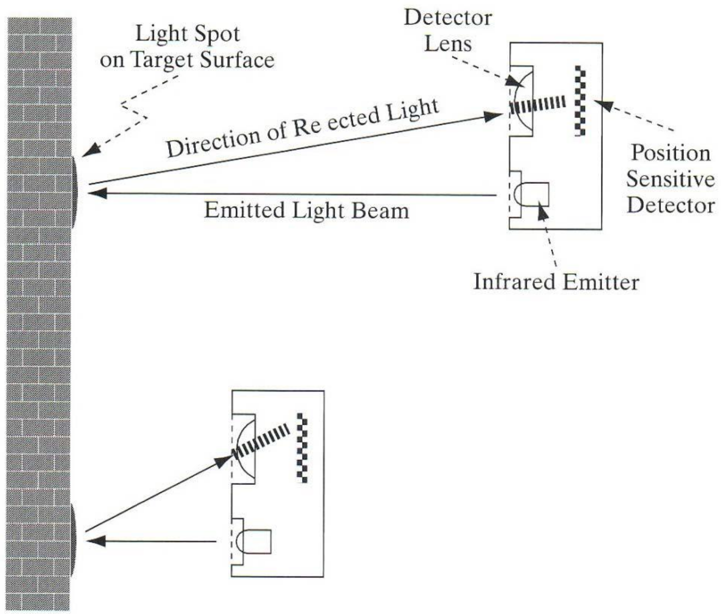
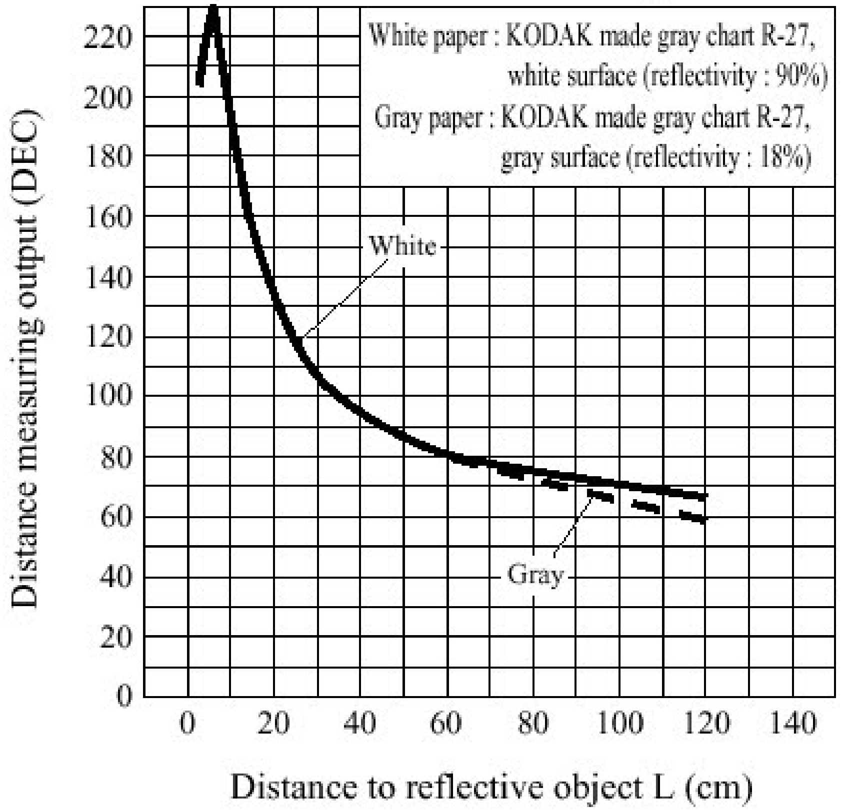


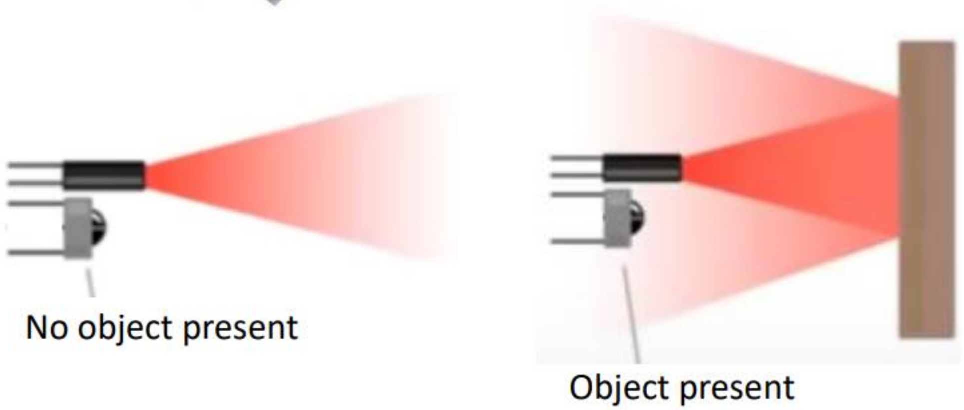
Fig. 1 Distance Measuring Output vs. Distance to Reflective Object



Location of the spot on the detector corresponds to the distance to the target surface.

IR Range Sensors

- Infrared (IR) sensor
  - Measures reflected light intensity which corresponds to distance
  - Range: 10 cm – 1 m
  - Wide detection cone
  - Can be also used to detect black vs white color (e.g., for a line detection)
  - Unaffected by material softness
  - Sensitive to object color and transparency
  - Background noises: The sensor fails to work if there are similar IR signals sources in the environment.
  - Relatively short distance

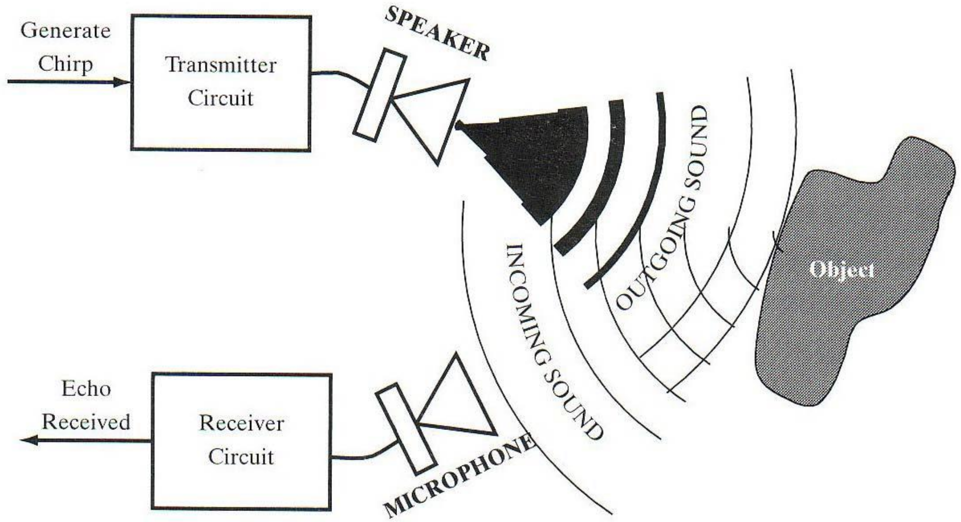


Ultrasonic Sensors

- Basic principle of operation:
  - Emit a quick burst of ultrasound (50kHz), (human hearing: 20Hz to 20kHz)
  - Measure the elapsed time until the receiver indicates that an echo is detected.
  - Determine how far away the nearest object is from the sensor

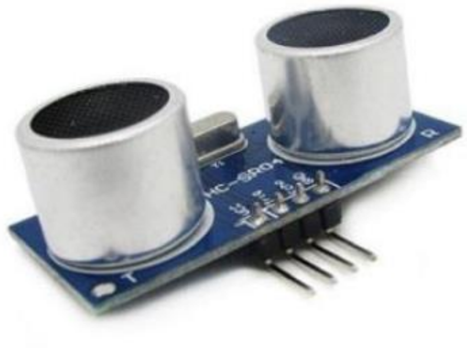
$$D = v \times t$$

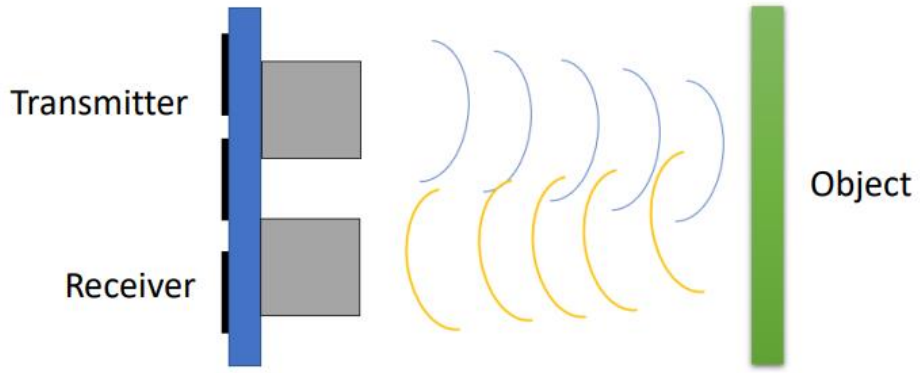
D = round-trip distance
v = speed of propagation (340 m/s)
t = elapsed time



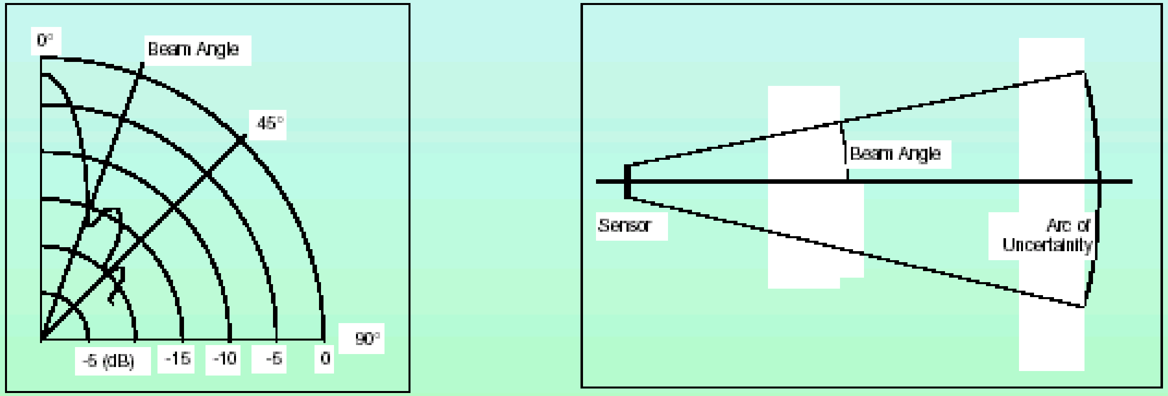
Ultrasonic Sensors

- Ultrasonic sensor
  - Measures time of reflected signal to return which corresponds to distance
  - Range: 2 cm – 3 m
  - Wide detection cone
  - Unaffected by object color and transparency
  - Sensitive to material softness
  - Relatively slow





Ultrasonic Sensors



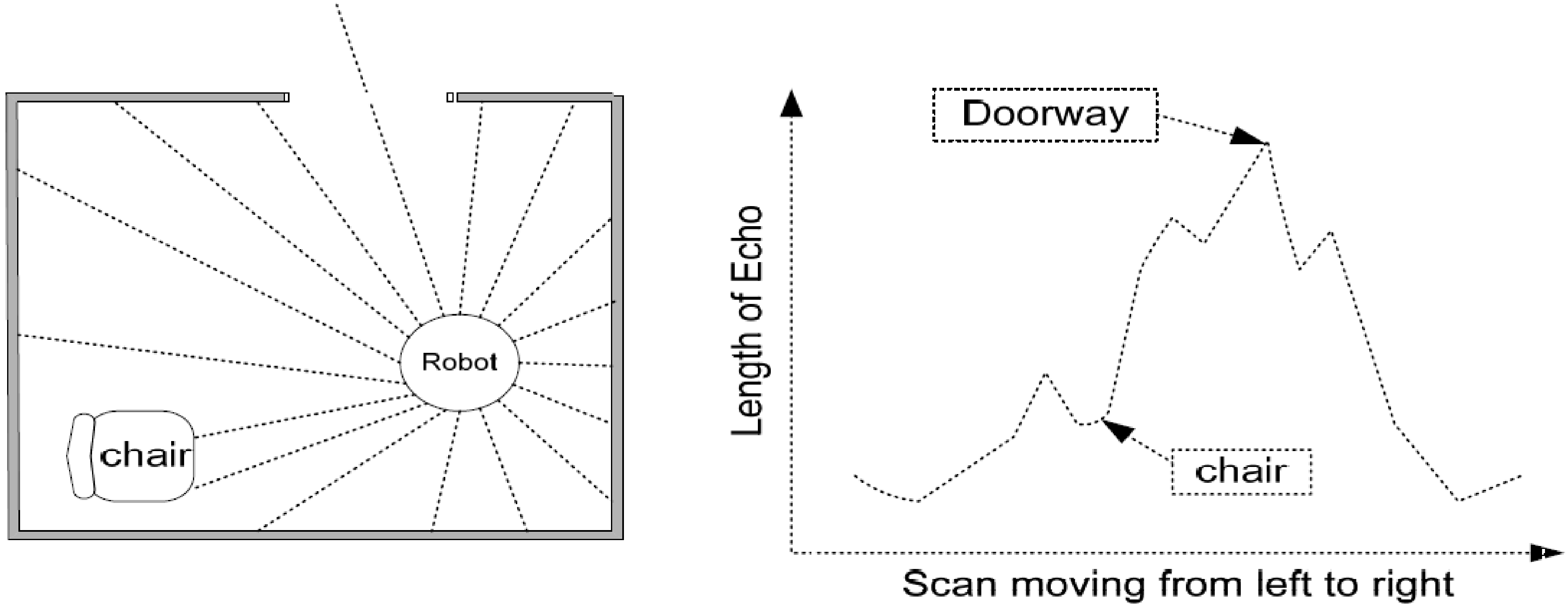
Sensor Specification

Sensor Model, angle = 15 degrees

- Ranging is accurate but bearing has a 30 degree uncertainty. The object can be located anywhere in the arc.
- Typical ranges are of the order of several centimeters to 30 meters.
- Another problem is the propagation time. The ultrasonic signal will take 200 msec to travel 60 meters. (30 meters roundtrip @ 340 m/s)

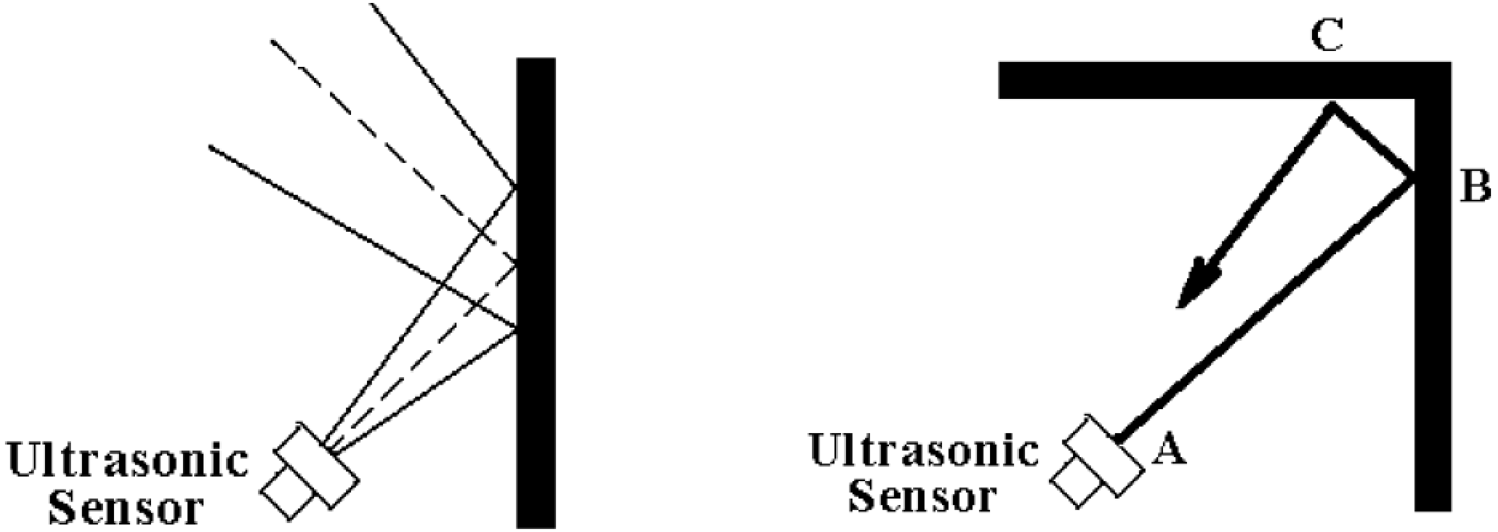
Ultrasonic Sensors

- Applications:
  - Distance Measurement
  - Mapping: Rotating proximity scans (maps the proximity of objects surrounding the robot)



Limitations of Ultrasonic Sensors

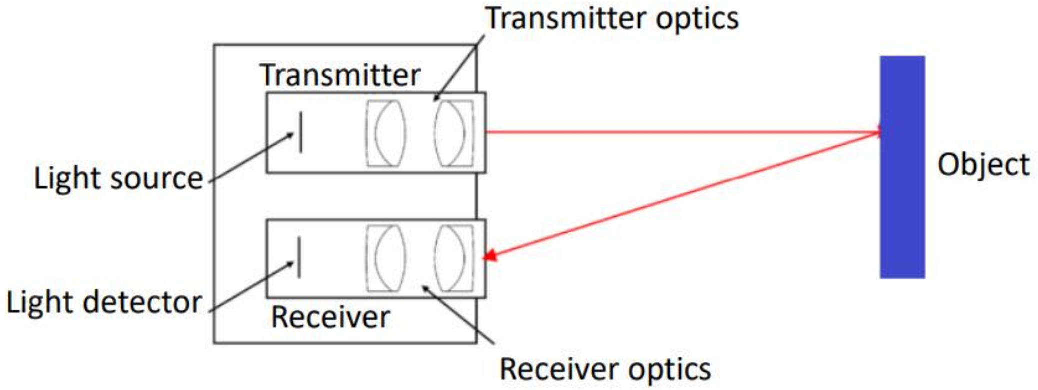
- Poor surface reflection: Surface materials absorb ultrasonic waves.
- Surface orientation affect the reflection of ultrasonic signals.



Surface orientation affects the performance

LIDAR Sensor

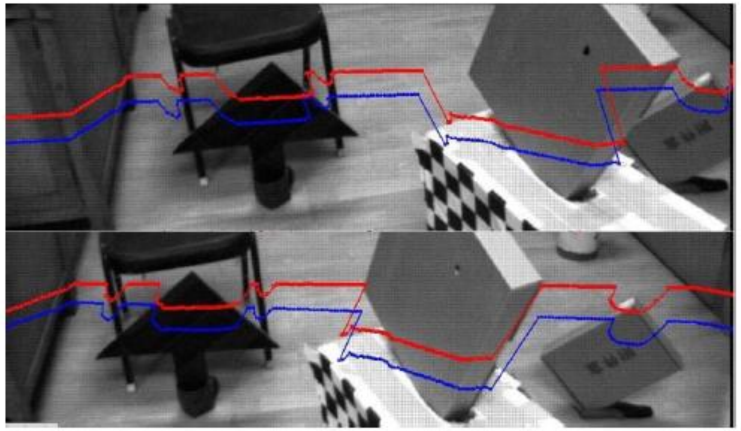
- LIDAR sensor (laser imaging, detection, and ranging)
  - Measures time of reflected signal to return which corresponds to distance
  - Range: 5 cm – 40 m
  - Fast and long range sensing
  - One single point (no cone)
  - Relatively expensive



Laser Ranger Finder

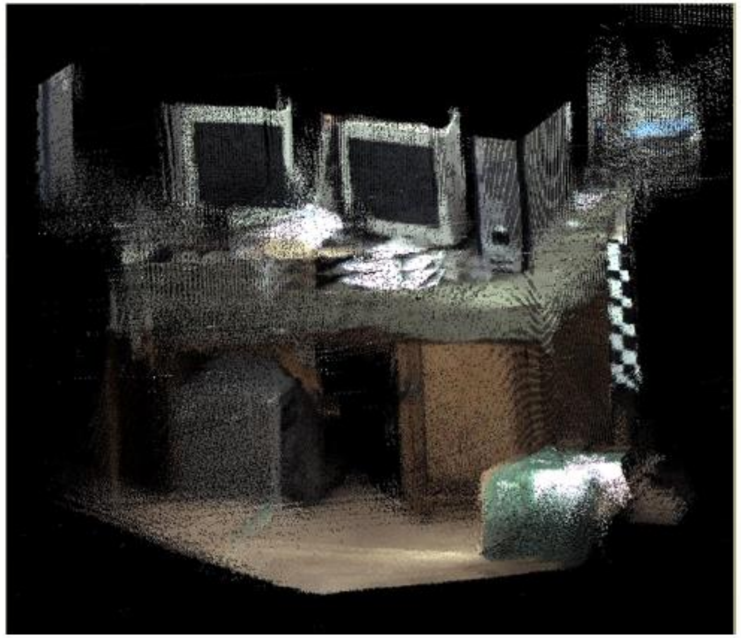
- The working principle: Triangulation.
  - Spin the laser strip and detect the reflected light
- Range 2-500 meters
- Resolution : 10 mm
- Field of view : 100 - 180 degrees
- Angular resolution : 0.25 degrees
- Scan time : 13 - 40 msec.
- These lasers are more immune to Dust and Fog

Example (Laser Range Finder)



Measurement slice

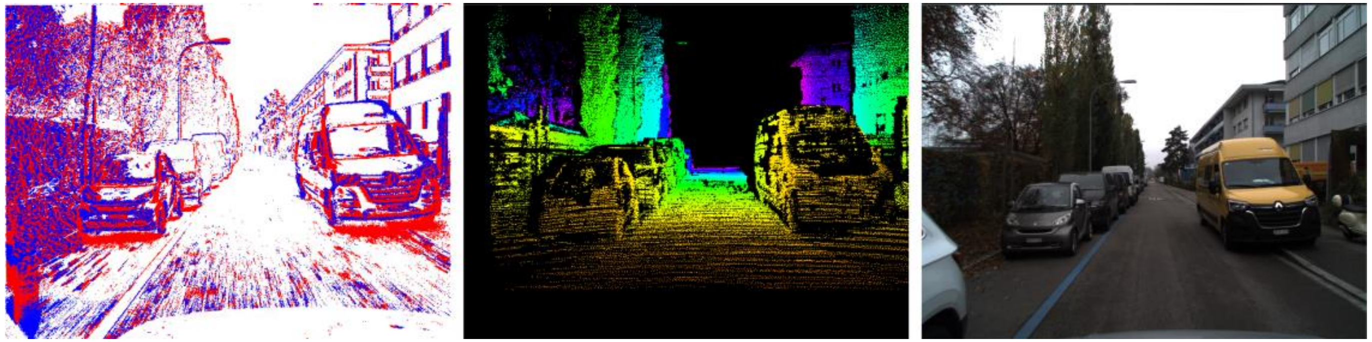
A scene



3D model constructed

VISION

- Vision provide the richest information
  - Geometric information
  - Texture
  - Color
  - Etc
- Many applications in robotics
  - Distance measurement
  - Object/person recognition
  - Control
  - …..
- Vision systems
  - Single camera, stereo camera
  - Active vision, passive vision



(a) (b) (c)

VS128 Dynamic Vision Sensor

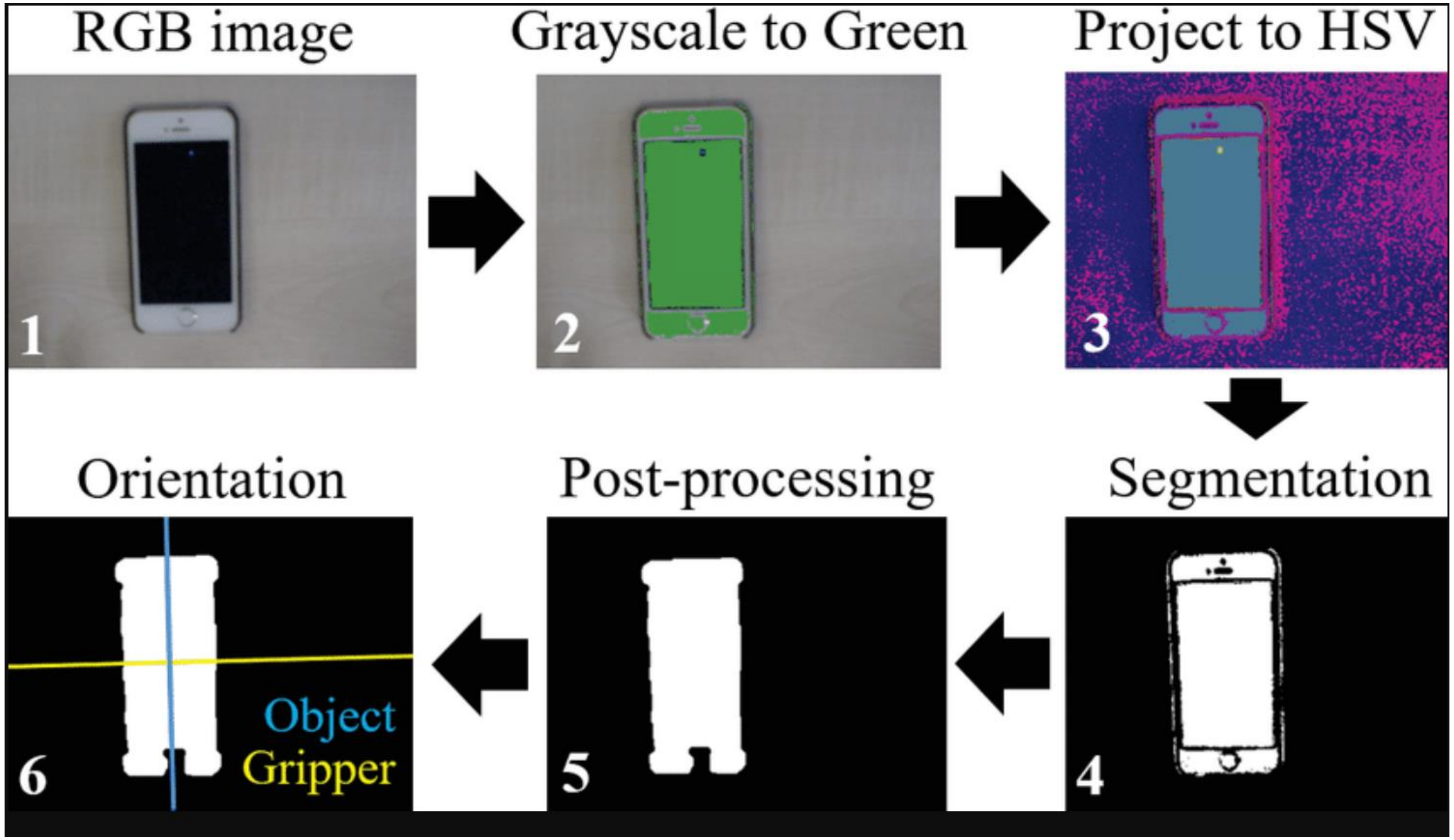
Intel Realsense Depth Camera

Logitech C930e

(a) Event camera
(b) Depth Stereo Camera
(c) Standard Camera

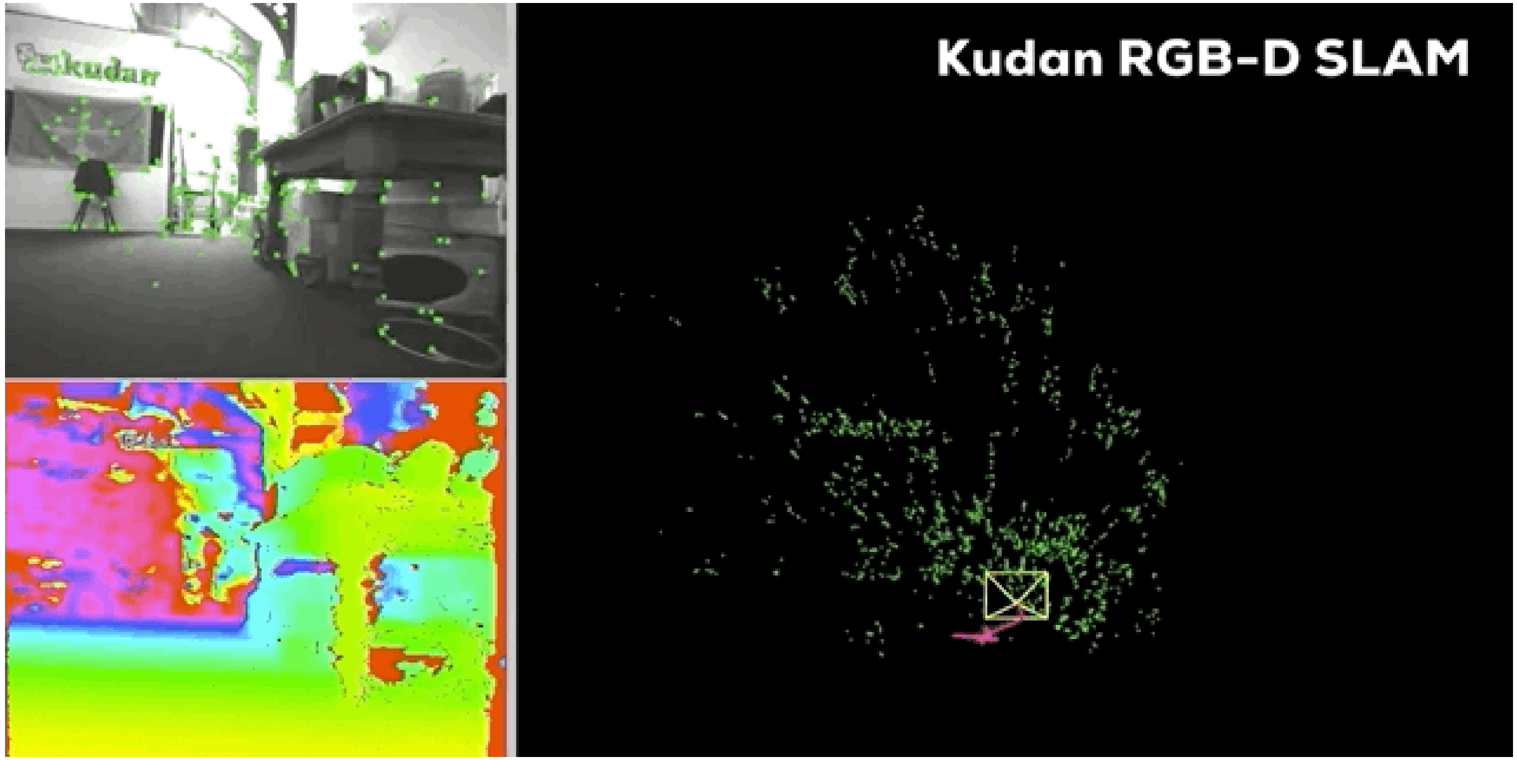
Source: https://rpg.ifi.uzh.ch/

Example (Image processing)



Mireia Ruiz Maym´et al, Fast Orient: Lightweight Computer Vision for Wrist Control in Assistive Robotic Grasping Research supported by eNHANCE*

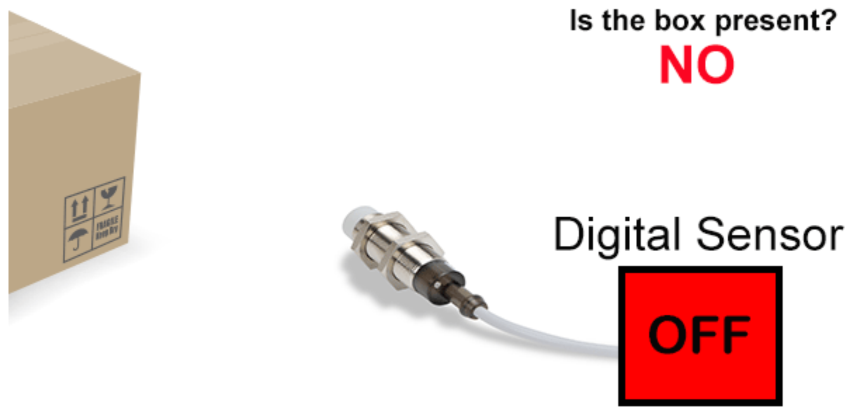
Positioning Sensor using Camera



Simultaneous localization and mapping (**SLAM**) is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it

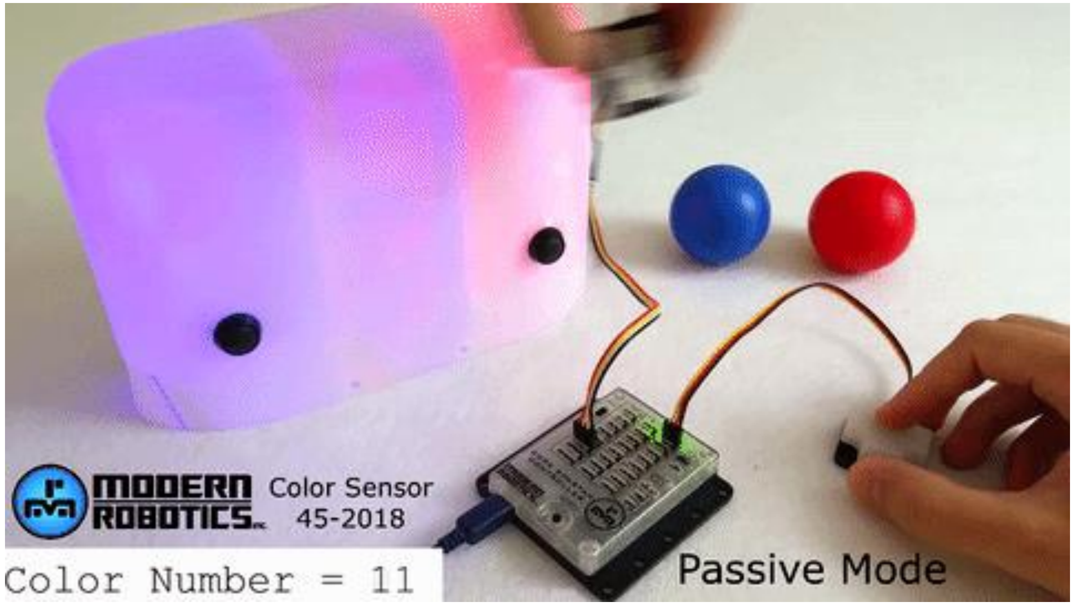
Proximity Sensors

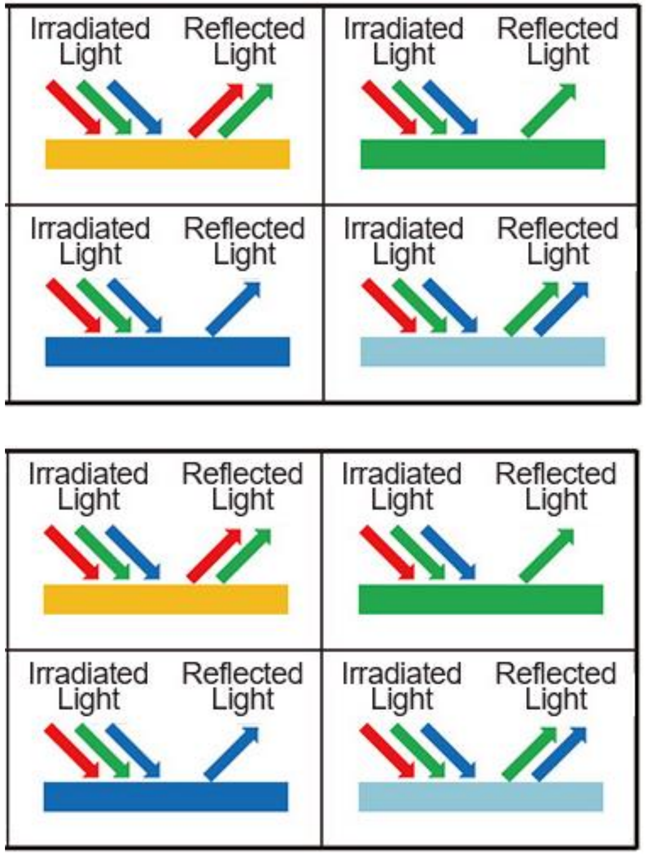
- To detect whether any object is close to a robot or touches a robot.
- Proximity sensor does not give distance, but only tells the existence of an object
- Typical sensors
  - IR proximity sensors (for any materials), Inductive proximity sensors (for ferocious material), etc



Proximity Sensors(con't)

- Typical sensors
  - **Photodiode, Color Sensor (Photodiode based)**

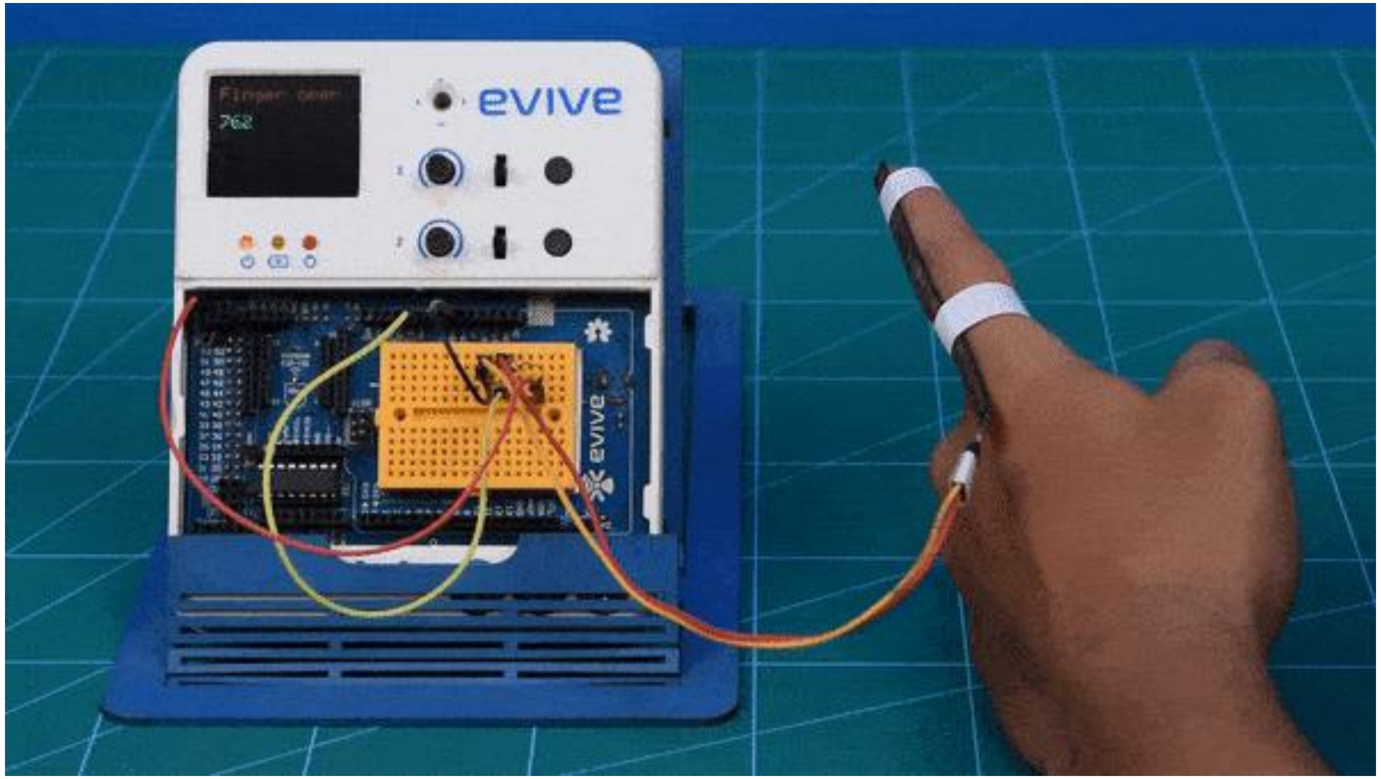




Photodiodes generate a current or voltage when illuminated by light.

- Their working principle is the same as that of IR sensors
- The differences lie in the wavelength of the lights they sense.

Flex Sensors



Source: https://thestempedia.com/tutorials/interface-flex-sensor-evive/

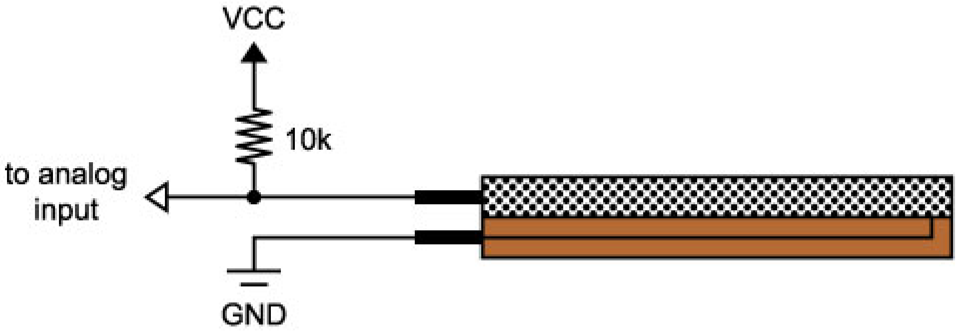


Fig. Example Usage

- Flex sensors are basically resistors that change value based on how much they're flexed.
- If they're unflexed, the resistance is about ~10 KΩ. *
- When flexed all the way the resistance rises to ~20 KΩ *

*) depends on sensors specification

Recall

For the following picture, determine which measurement signal is internal and which is external according to the robot's point of view !

No	Fenomena yang dideteksi	Internal / Eksternal	Sensor/s
1	Robot menghadap kemana ?	Internal	Magnetometer
2	Robot miring atau tegak ?	Internal	Gyroscope
3	Bola dimana ?	Eksternal	Camera
4	Ada lawan didepan atau tidak ?	Eksternal	Camera
5	Leher menunduk berapa derajat?	Internal	Encoder
6	Permainan sedang berjalan atau tidak ? (WiFi)	Eksternal	Wifi
7	Kaki kanan menginjak lantai atau tidak ?	Eksternal	Strain gauge
8	Body robot bergoyang kemana ?	Internal	Accelerometer
9	Sendi kaki overload atau tidak ?	Eksternal	Torque Sensor
10	Seberapa jauh gawang dari robot ?	Internal	Depth Camera/Lidar
11	Dimana posisi robot relative terhadap lapangan ?	Eksternal	Camera
12	Robot jatuh kebelakang atau ke depan ?	Internal	Accelero / Gyro

Play around with Sensor Simulation

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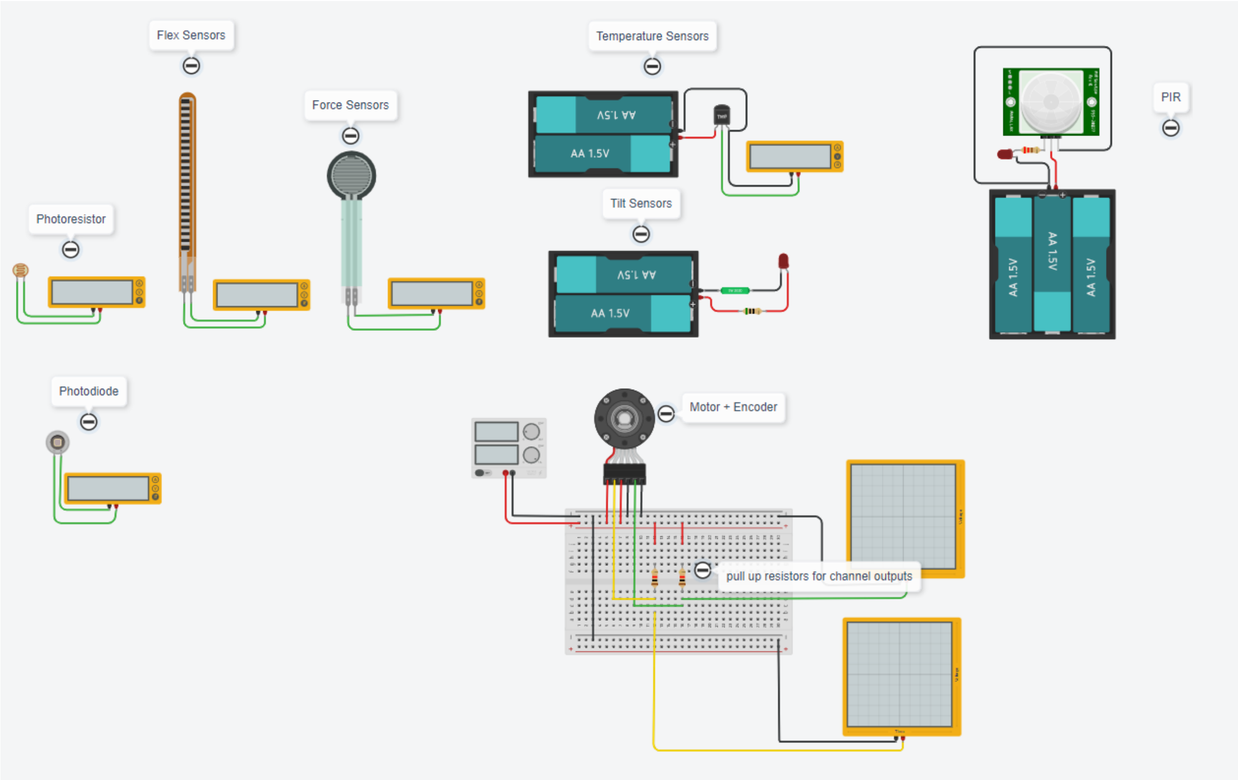

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https://www.tinkercad.com/things/bvW79ERo3xB-epic-amur/editel?sharecode=tcUIxAbchjI25GHUvPHzp_xSF_RzRw34Tj-Xq0tAMSk

Terima Kasih