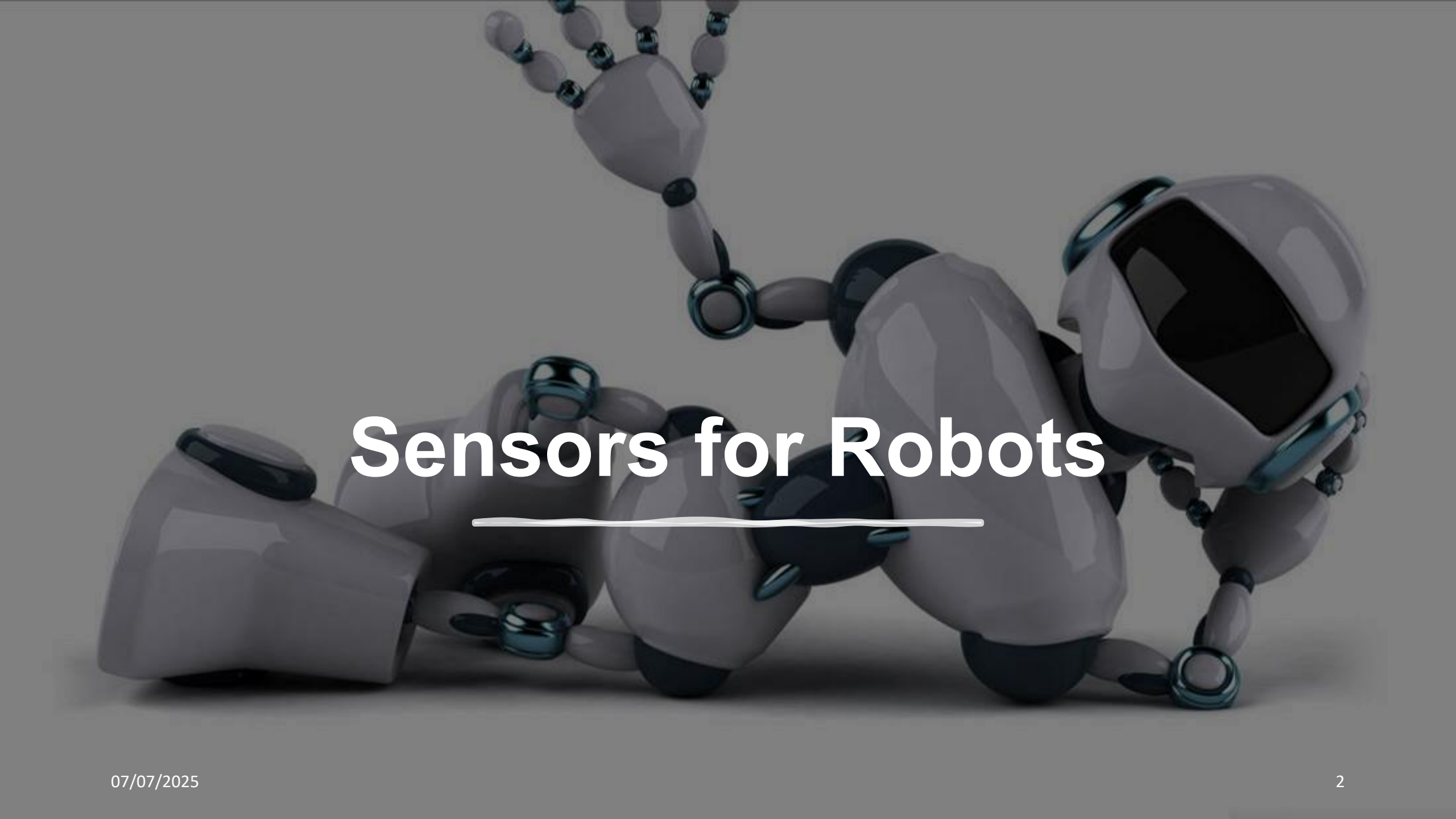
ROBOT SENSORS

Geeth Karunarathne

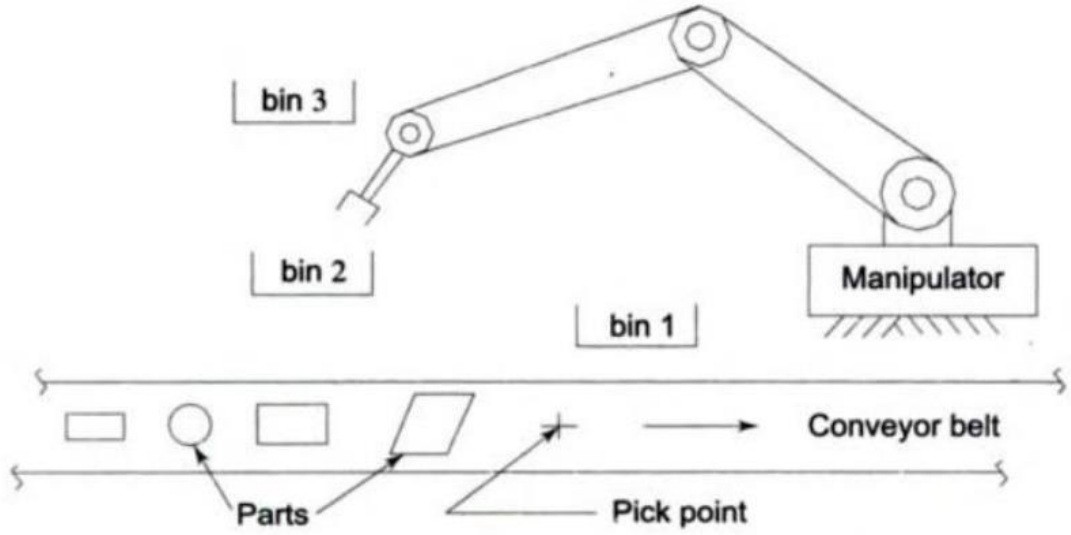


Sensors for Robots

Introduction

- There are two control mechanisms
  - Open-Loop control system
  - Closed-Loop control system

- Joint and end-effector position, velocity, acceleration.



Sensors

- Different types of sensors that are commonly used in various applications. All these sensors are used for measuring one of the physical properties like temperature, resistance, capacitance, conduction, heat transfer etc.

Industrial robot requires sensory feedback to

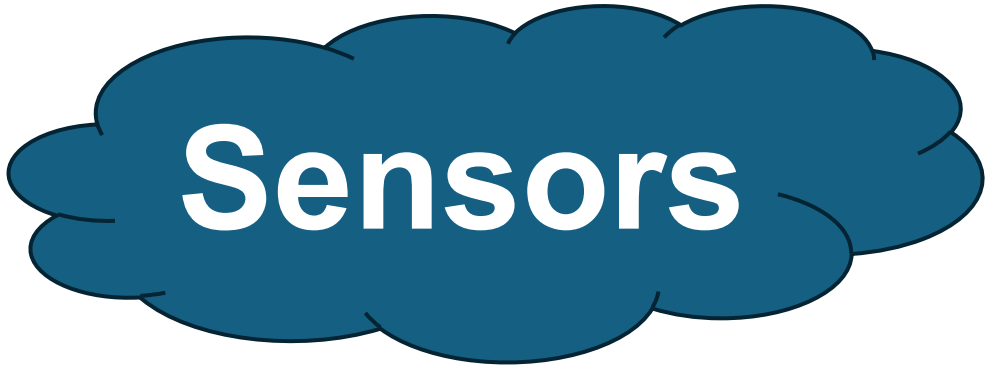
- Locate randomly placed object;
- Allow for variations in shape of objects;
- Protect against dangerous and unexpected situations. Especially if the robot must work close to humans:
- Allow “intelligent” recovery form error conditions;
- Perform quality control.
- The main objective of incorporating sensors in robotic system is to enable robots to work in nonstructural and random environments.
- Sensors will make robots more intelligent. But the associated robotic software must have the ability to receive data from the sensors and to process the necessary real time information and commands needed for the decision making

Sensing

- The 5 human sensors
  - Sight - eyes
  - Hear - Ears
  - Smell - Nose
  - Touch - Skin
  - Taste - Tongue

Extended ranges and modalities

- Vision outside the RGB spectrum
- Infrared Camera, see at night
- Radar and optical (laser) range measurement
- Hearing outside the 20 Hz – 20 kHz range
- Ultrasonic range measurement
- Chemical analysis beyond taste and smell
- Radiation: alpha, beta, gamma-rays, neutrons, etc



Humidity Sensor

Color Sensor

Proximity Sensor

Temperature Sensor

IR (Infrared) Sensor

Touch Sensor

Pressure Sensor

Accelerometer

Light Sensor

Gas Sensor

Magnetic Sensor

Smoke Sensor

Ultrasonic Sensor

Position Sensor

Tilt Sensor

Alcohol Sensor

Sensors used in robot navigation

- Resistive sensors
  - bend sensors, potentiometer, resistive photocells, ...
- Tactile sensors
  - contact switch, bumpers
- Infrared sensors
  - Reflective, proximity, distance sensors…
- Ultrasonic Distance Sensor
- Inertial Sensors (measure the second derivatives of position)
  - Accelerometer, Gyroscopes,
- Orientation Sensors
  - Compass, Inclinometer
- Laser range sensors
- Vision
- Global Positioning System

Classification of Sensors

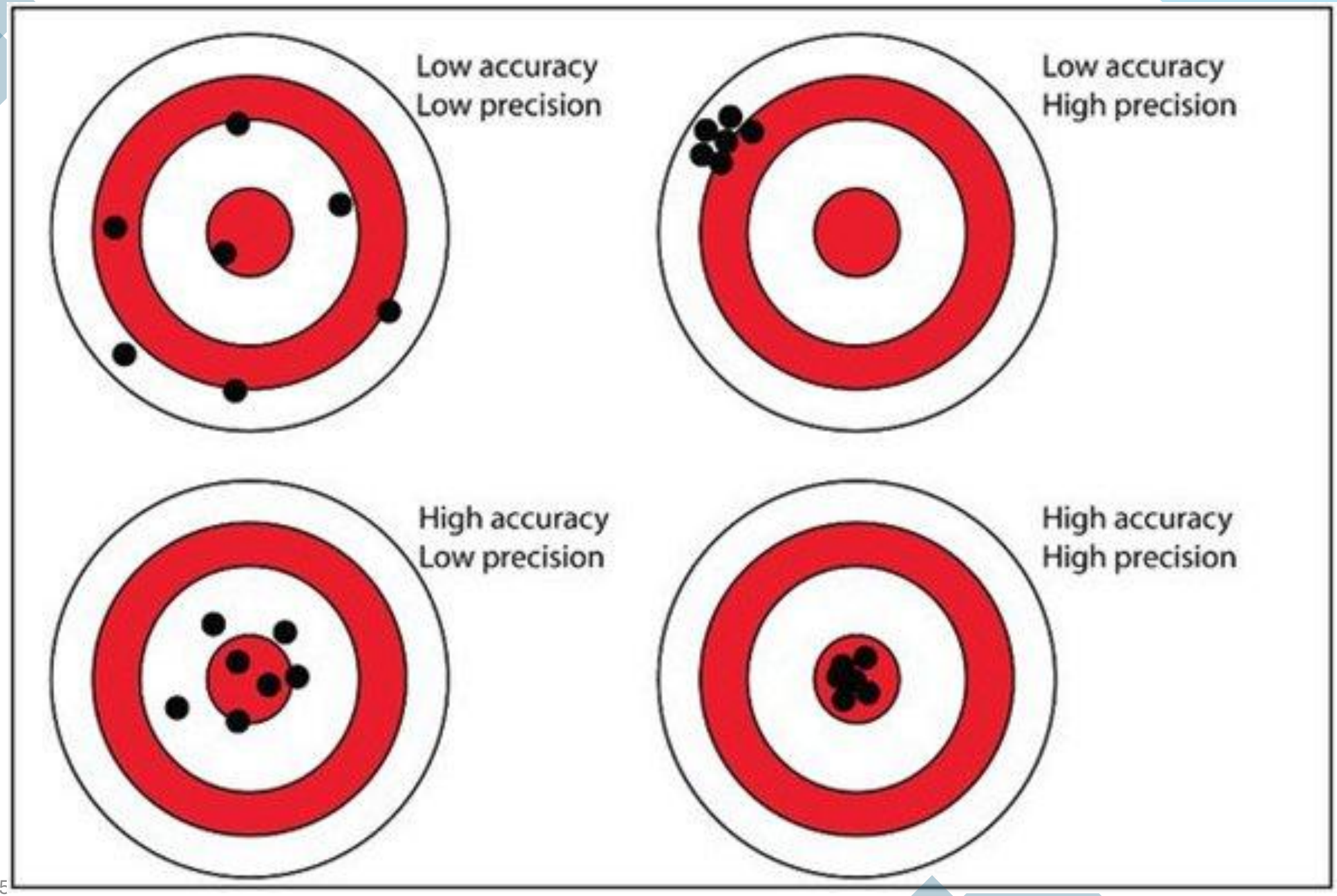
- Internal state (proprioception) v.s. external state (exteroceptive)
  - feedback of robot internal parameters, e.g. battery level, wheel position, joint angle, etc,
  - observation of environments, objects
- Active v.s. non-active
  - emitting energy into the environment, e.g., radar, sonar
  - passively receive energy to make observation, e.g., camera
- Contact v.s. non-contact
- Visual v.s. non-visual
  - vision-based sensing, image processing, video camera

In general, robotic sensors can be divided into two classes:

- **Internal state sensors** - device being used to measure the position, velocity and acceleration of the robot joint and/or end-effector.
- These devices are potentiometer, tachometers, synchros, resolvers, differential transformers, optical interrupters, optical encoders and accelerometer.
- **External state sensors** – device being used to monitor the relationship between the robot kinematics and/or dynamics with its task, surrounding, or the object being manipulated.

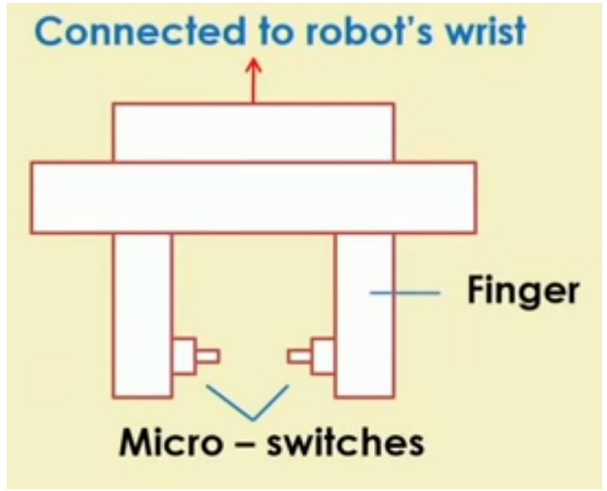
Sensor Selection

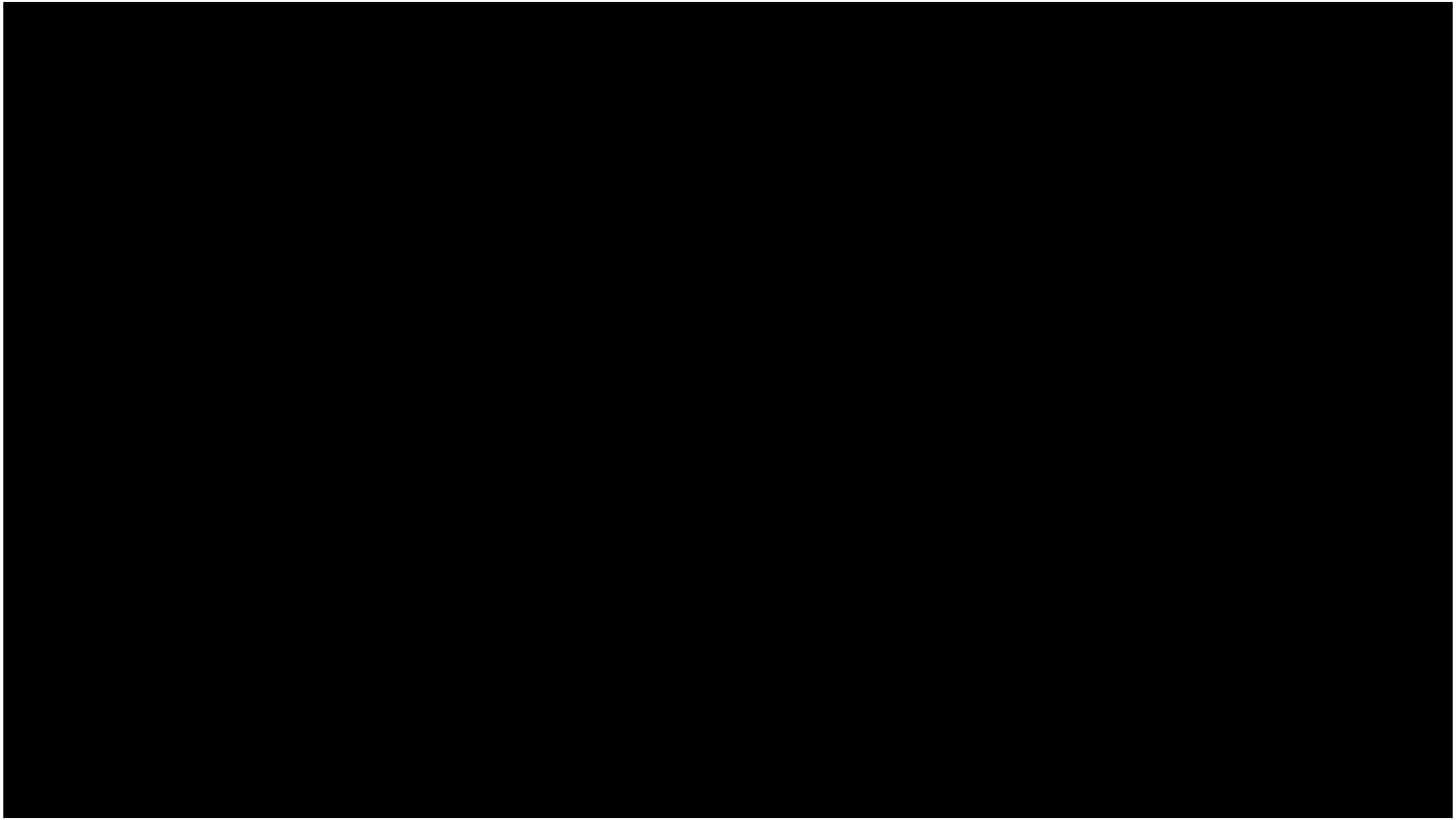
- **Range**: Difference between the maximum and minimum values of the input that can be measured
- **Response**: Should be capable of responding to the changes in minimum time
- **Accuracy**: Deviation from exact quantity
- **Sensitivity**: Change in output/change in input
- **Linearity**: Constant sensitivity
- **Repeatability**: Deviation from reading to reading, when these are taken for a number of times under identical conditions
- **Resolution**: The smallest detectable incremental change of input parameter that can be detected in the output signal


Low accuracy
Low precision
Low accuracy
High precision
High accuracy
Low precision
High accuracy
High precision

Touch Sensor

- To indicate whether a contact has been made between two objects or not.
- Does not determine the magnitude of the contact force.
- Examples: Micro-switch, Limit switch





https://www.youtube.com/results?search_query=micro+switch%2F+limit+switch

IR Sensor

- There is a transmitter and a receiver.
- If an object is placed in-front of the detection region, the beam gets reflected back to the sensor.
- The range can e controlled.
- IR sensors with three pins usually are only digital.
- IR sensors with three or four pins gives digital values as well as analog values.

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

PIR Sensor

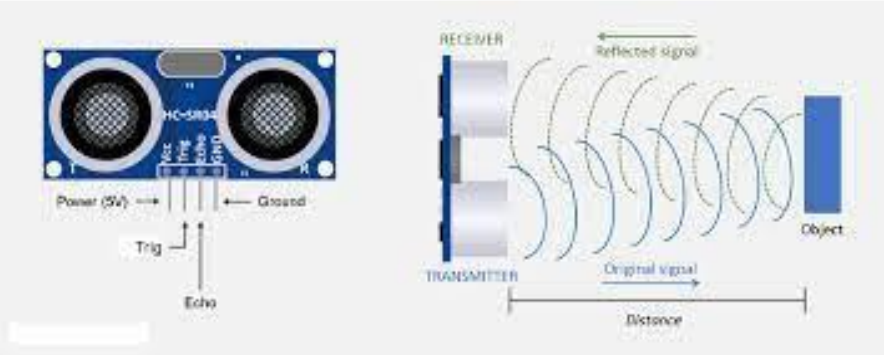
- PIR sensors are also known as pyroelectric Infrared sensor, Passive Infrared sensor or IR motion sensor.
- Detect the difference in temperature, thermal radiation, human body or an animal.
- PIR sensor operates with the radiation of body heat.
- The hotter the detected object, there will be more emission occurs in PIR sensor.

https://www.youtube.com/watch?v=6Fdrr_1guok

Ultrasonic Sensor

- A non-contact type device that can be used to measure distance as well as velocity of an object (using doppler shift property).

- Works based on the properties of the sound waves with frequency greater than that of the human audible range.



https://www.youtube.com/watch?v=dPZ9izkt1pY

Lidar Sensor

- Laser based sensor system.
- Considered as one of the most accurate schemes for generating spatial information about the shape and surface characteristics of any object.
- Differences in laser return times and wavelengths can be used to make digital 3-D representations of the target.

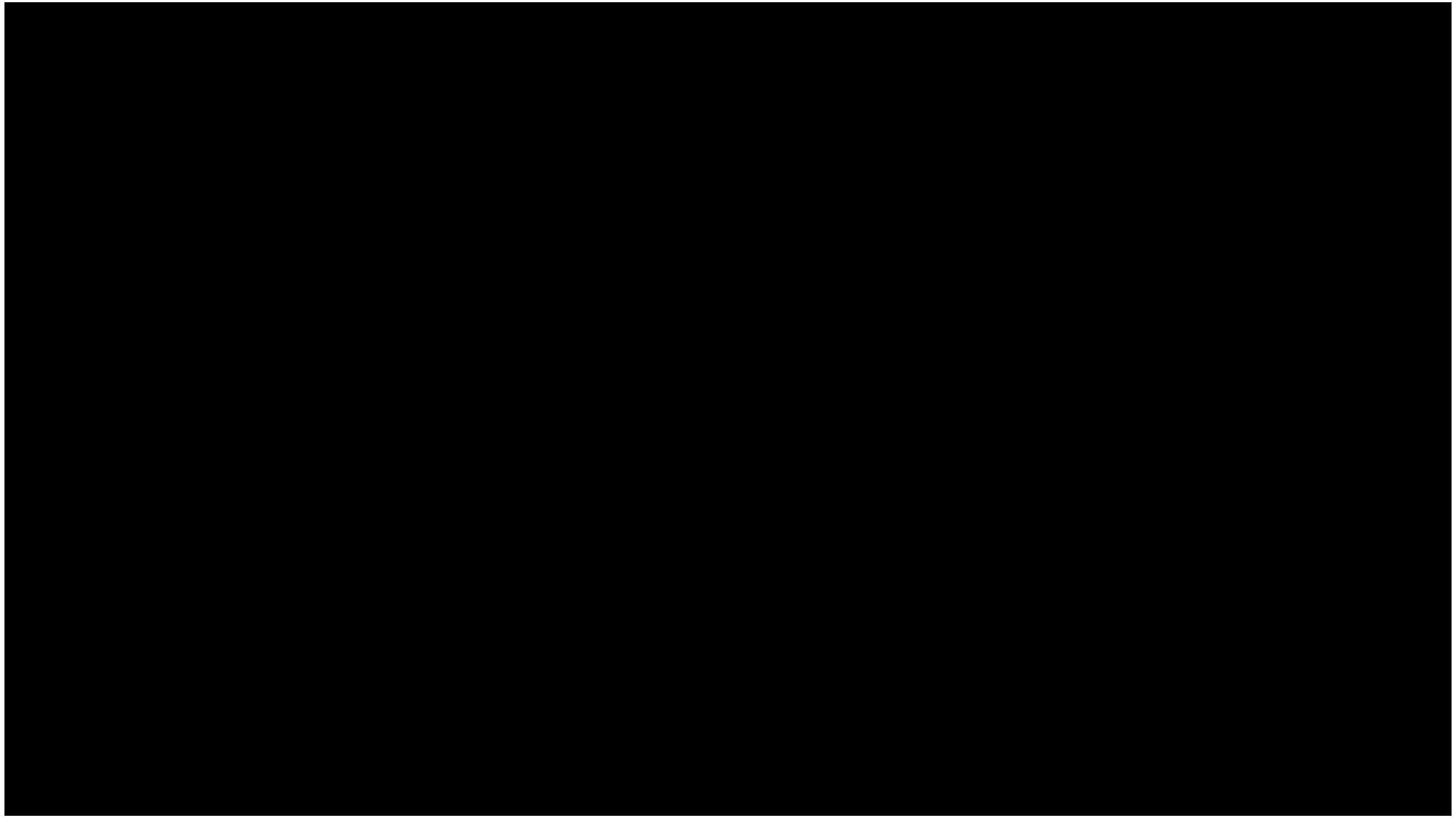
https://www.youtube.com/watch?v=vMwRfwJri4s

Robotic Force Torque Sensor

- A robotic force torque sensor is a device that measures force and torque when they are applied.
- Through this, a signal is created, measured, recorded and used as a feedback signal for robot interactions.
- The most widely used sensor in robotics is a 6-axis force torque sensor where 3 forces and 3 torques can be measured.

Operation of a force torque sensor

https://www.youtube.com/watch?v=d-zVBr-oy-s



Why force/torque sensor?

https://www.youtube.com/watch?v=b4nz_hAh7qs&t=65s

Position Encoder

- An encoder is a sensor that converts motion or position into a corresponding electrical signal.
- An encoder can be used to determine the position, speed or direction of a moving object.
- Position encoder is a type of sensor used to determine the position of an object, typically its rotational or linear displacement.

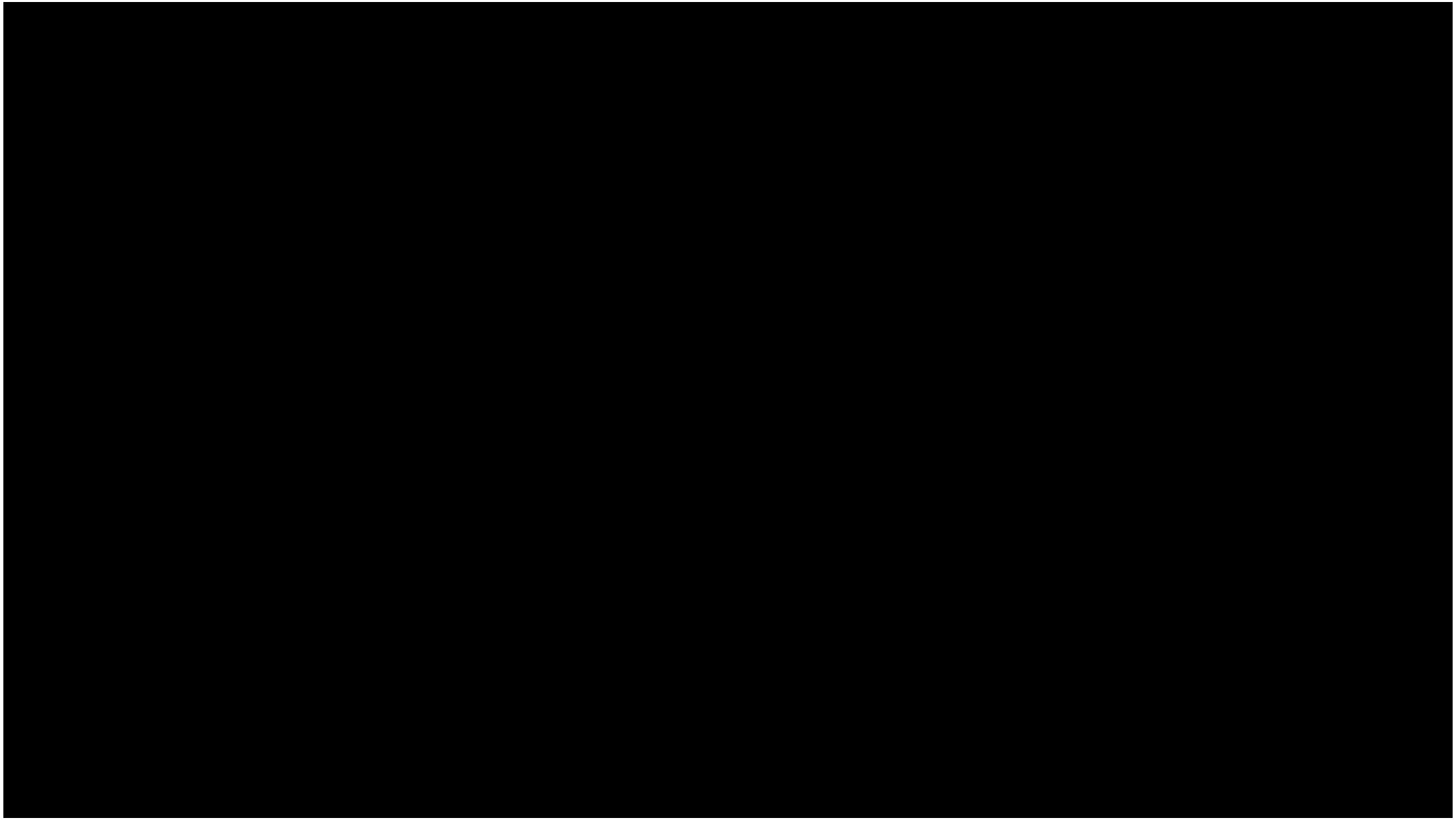
Types of Position Encoders

- Most common types of encoders
  - Rotary Encoders
  - Linear Encoders
  - Angle Encoders

- Types of position encoders
  - Rotary Position Encoders
  - Linear Position Encoders

Types of Position Encoders cont…

- An encoder can be categorized by means of its output
  - Incremental encoders; generates a series of pulses which can be used to determine position and speed.
  - Absolute Encoders; generates unique bit configurations to track position directly.



https://www.youtube.com/watch?v=-Qk--Sjgq78&t=224s

Types of Position Encoders cont…

- There are four types of information necessary to rotate the motor with high accuracy
  - Rotation amount
  - Rotational speed
  - Rotational direction
  - Rotational position

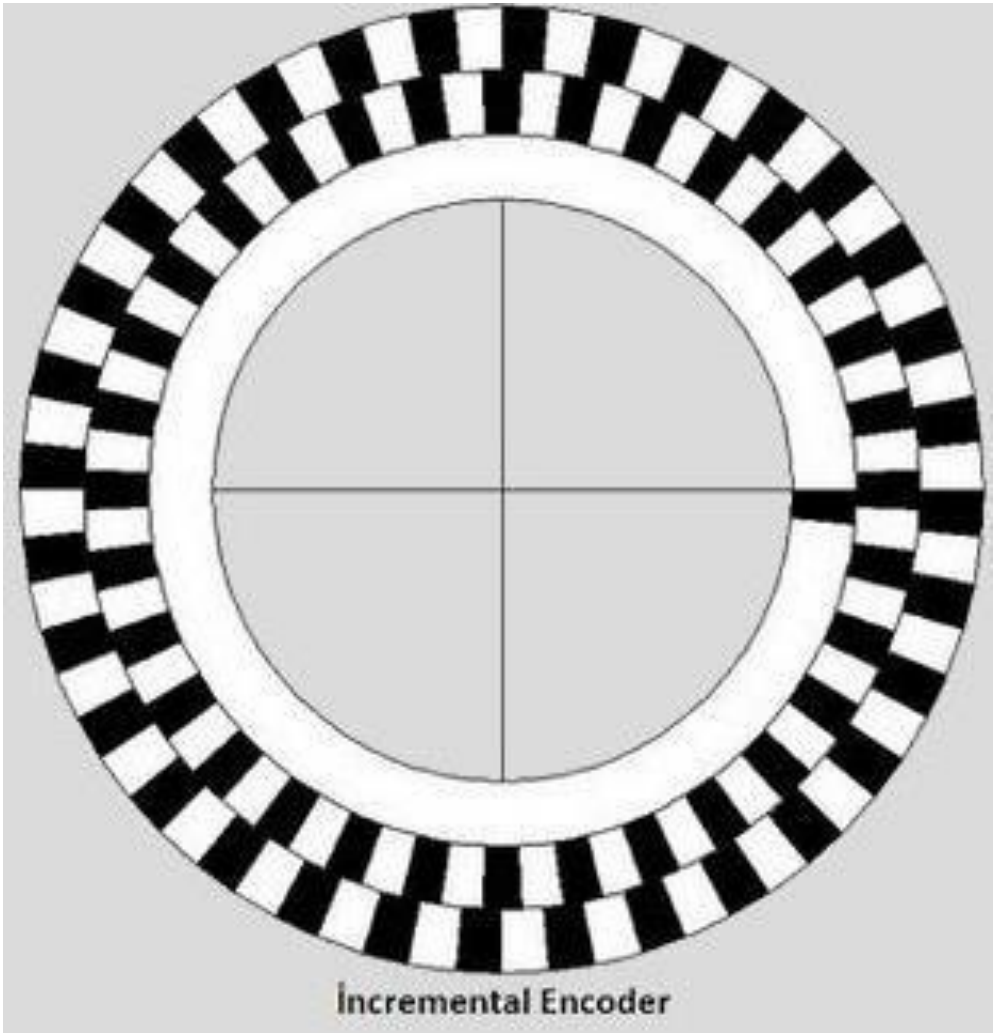
Incremental and Absolute

- There are two ways that encoders represent rotation and angle information: a relative angle and an absolute angle.
- Relative angle: How many angles have you moved before and after moving?
- Absolute angle: How many degrees are you in now from the home position?

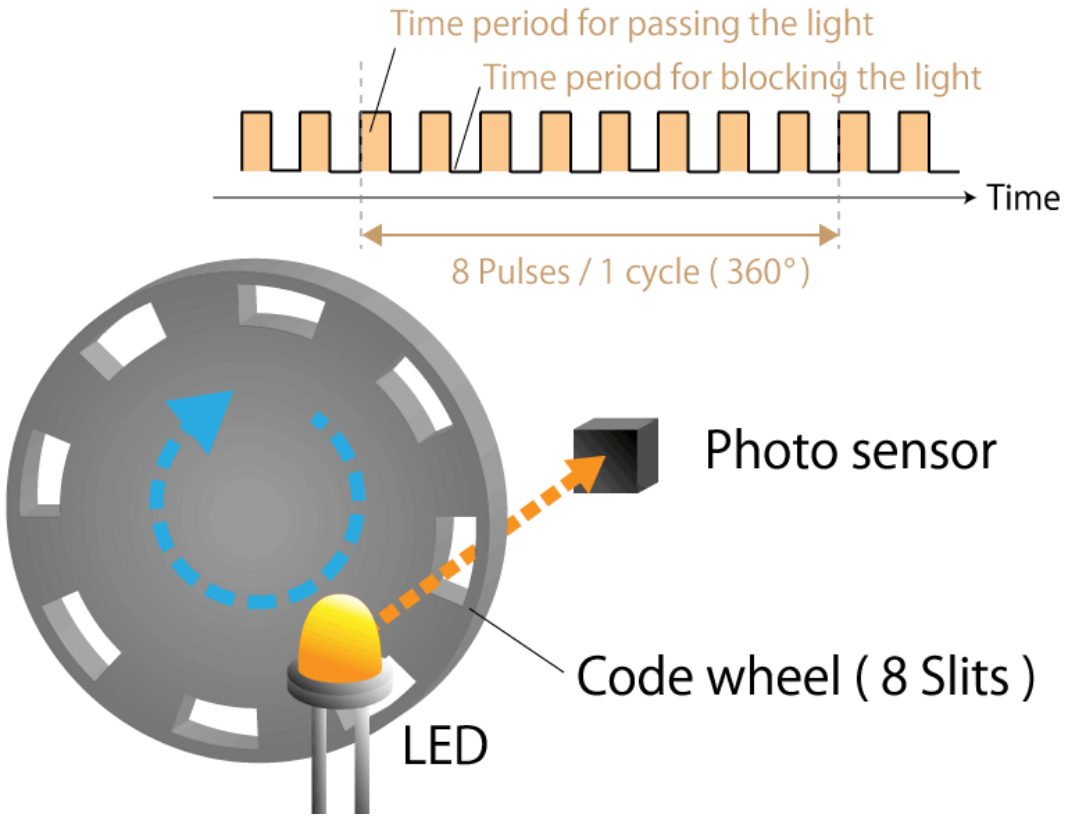
Incremental Encoders

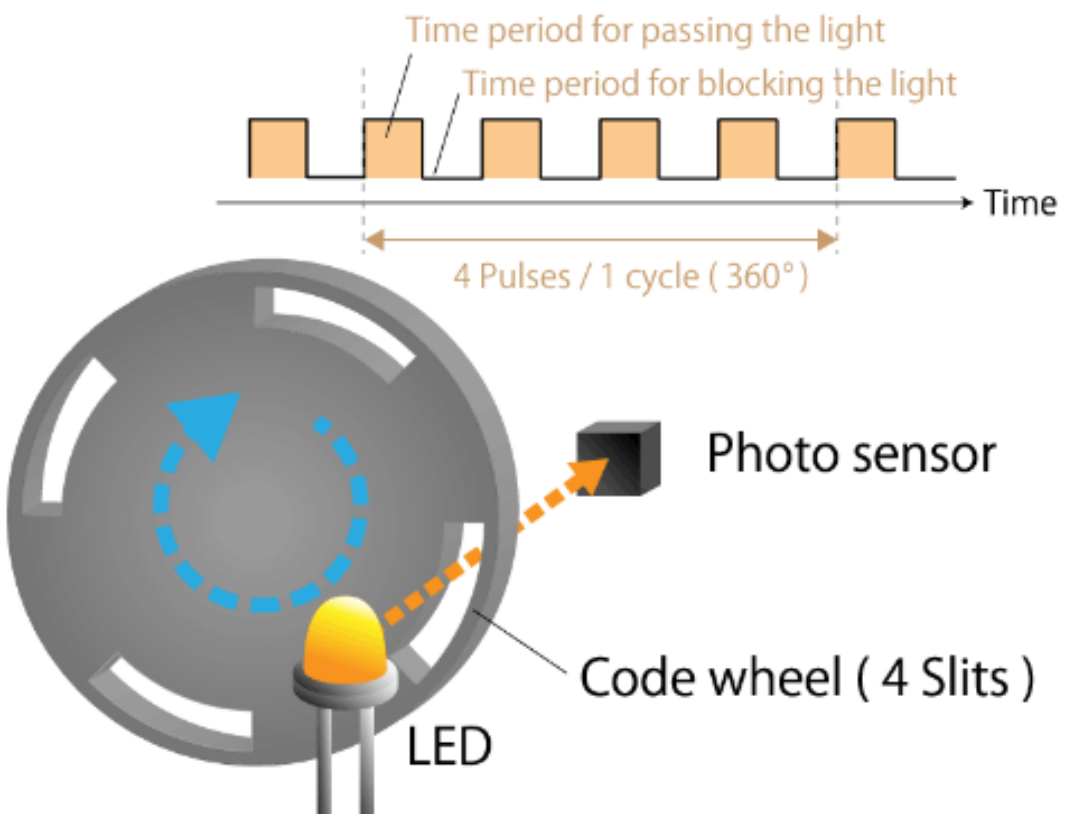
- An encoder that detects the amount of movement from one position to the next is called a relative angle detection type.

- Taking optical encoder as an example: It generates pulses when a disk with a slit (hole) in the radial direction rotates.



Counting the number of pulses shows the angular change (movement) of the disk

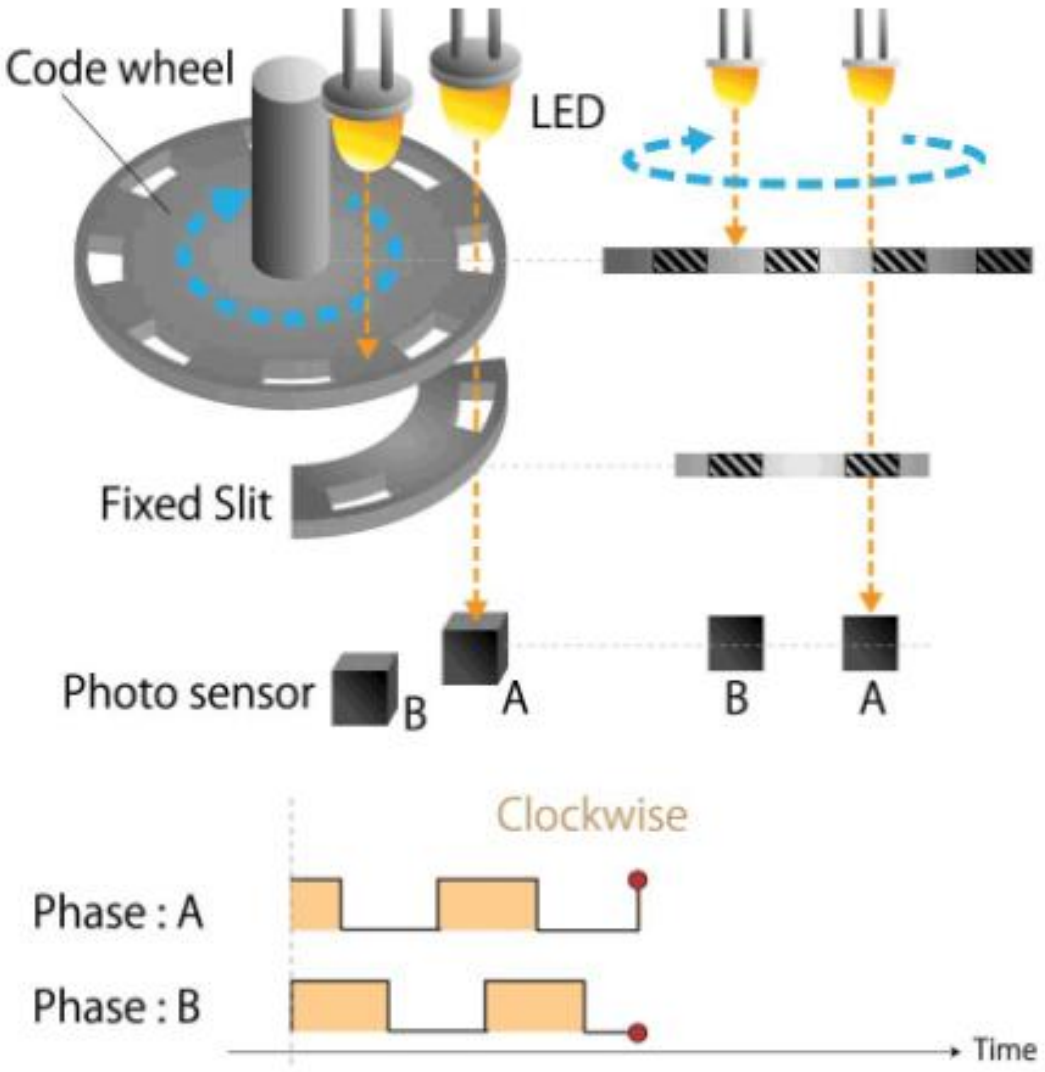




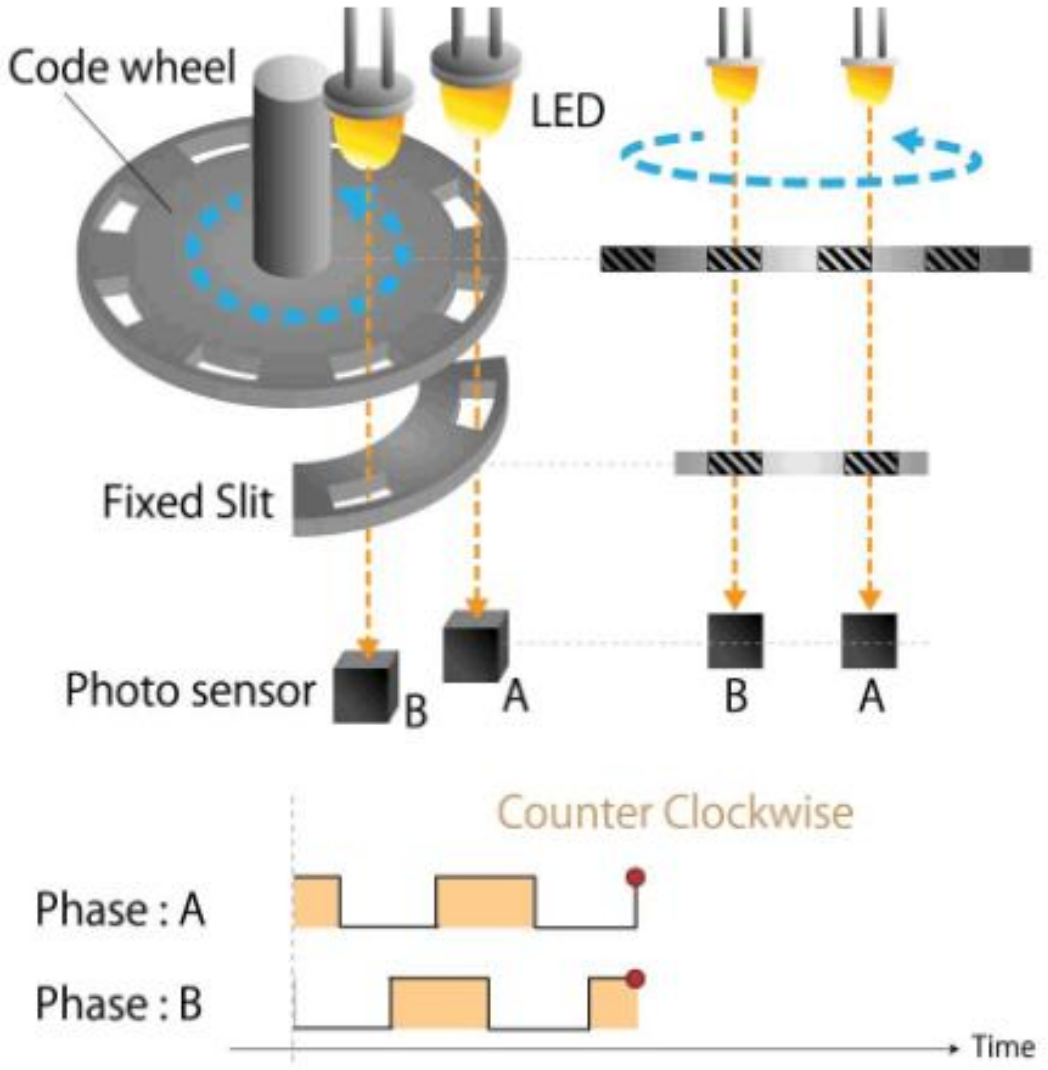
Counting the number of pulses shows the angular change (movement) of the disk

- This method cannot recognize that the rotational direction has changed.
- Therefore, two pulses whose phases are shifted by a quarter cycle are generated. These two pulses are generally called phase A and phase B.

Clockwise Rotation



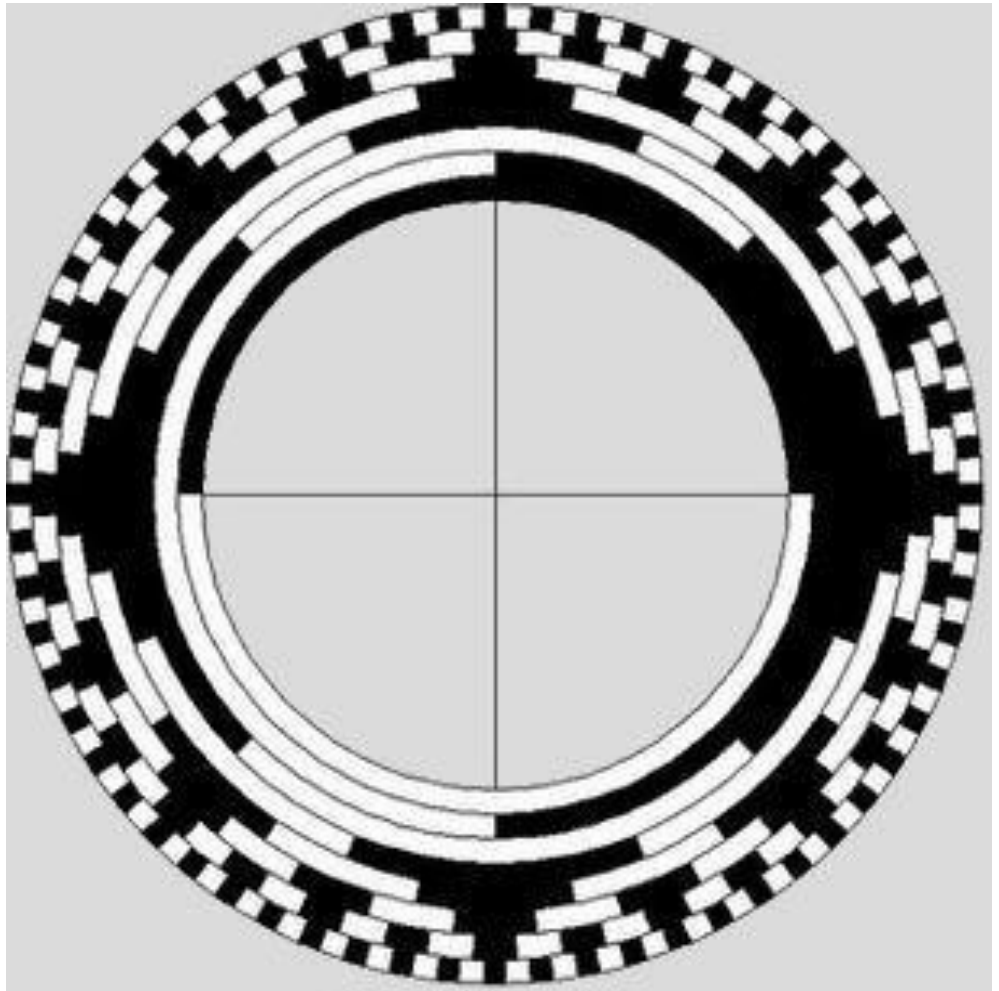
Counterclock wise Rotation



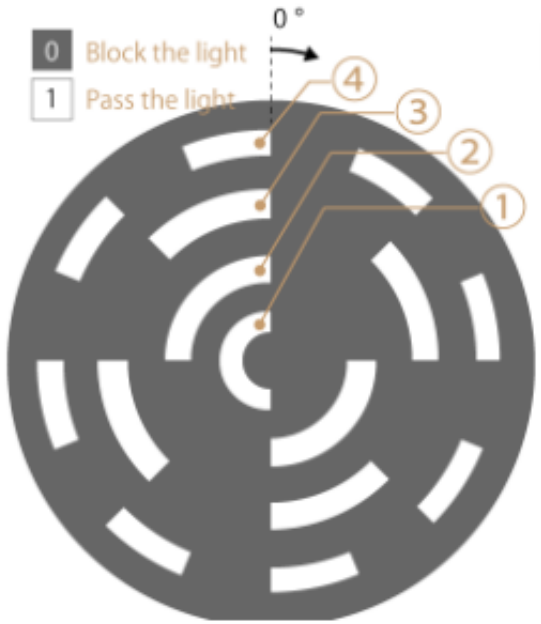
Absolute Encoders

- An encoder that detects how far from the home position is called an absolute angle detection type.

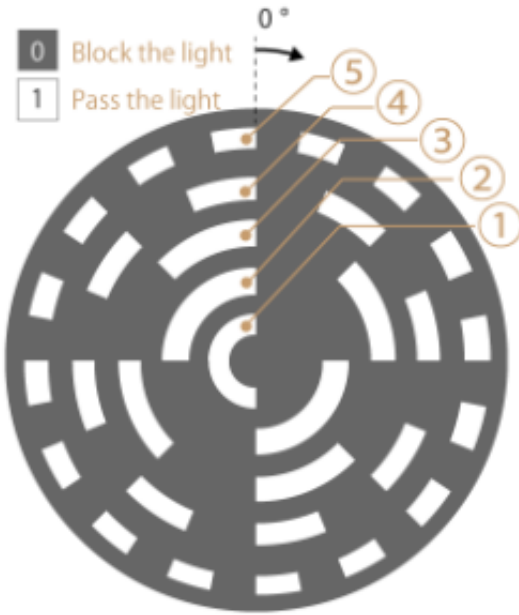
- The absolute angle detection type encoder outputs the current absolute angle in a digital serial code or an analog voltage in response to instructions from the microcomputer. Such an output way is called an absolute method.



Absolute Encoder



Angle [degrees]	①	②	③	④
0.0	0	0	0	0
22.5	0	0	0	1
45.0	0	0	1	0
67.5	0	0	1	1
90.0	0	1	0	0
112.5	0	1	0	1
135.0	0	1	1	0
157.5	0	1	1	1
180.0	1	0	0	0
202.5	1	0	0	1
225.0	1	0	1	0
247.5	1	0	1	1
270.0	1	1	0	0
292.5	1	1	0	1
315.0	1	1	1	0
337.5	1	1	1	1

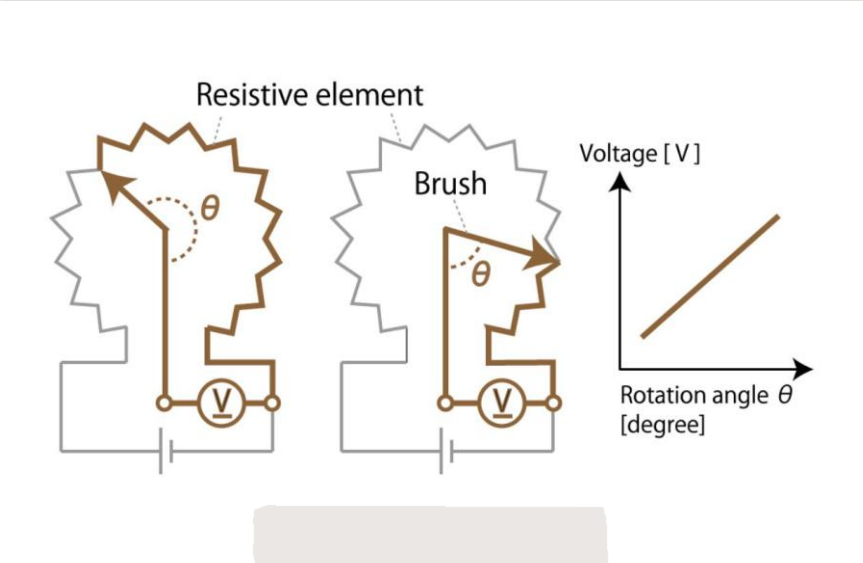


Angle [degrees]	①	②	③	④	⑤
0.00	0	0	0	0	0
11.25	0	0	0	0	1
22.50	0	0	0	1	0
33.75	0	0	0	1	1
45.00	0	0	1	0	0
56.25	0	0	1	0	1
67.50	0	0	1	1	0
78.75	0	0	1	1	1
90.00	0	1	0	0	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
315.00	1	1	1	0	0
326.25	1	1	1	0	1
337.50	1	1	1	1	0
348.75	1	1	1	1	1

Classification of Encoders

- An encoder is classified into four types
  - Mechanical Encoders
  - Optical Encoders
  - Magnetic Encoders
  - Electromagnetic Induction Encoders

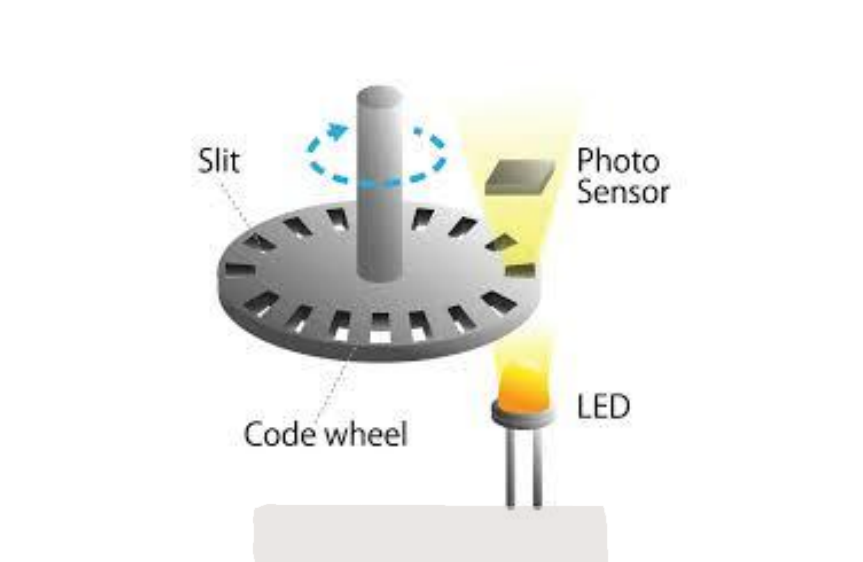
Mechanical Encoders



- This method detects the rotational position with a variable resistor whose electrical resistance changes in proposition to the rotation angle. Such a mechanical encoder is generally called a potentiometer.

- When the slider moves on resistors, the resistance value of the potentiometer changes in proposition to the moving distance of the slider.

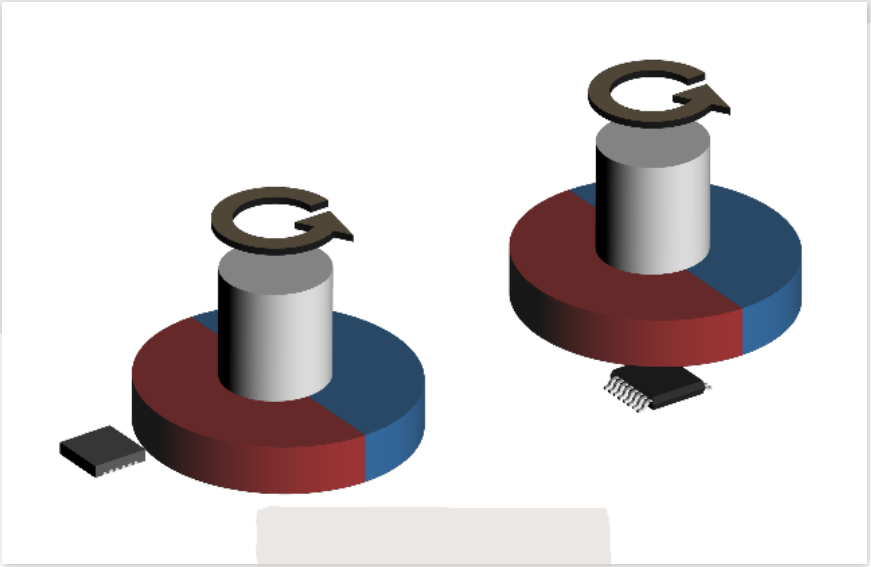
Optical Encoders



- This is a method that uses a light sensor to detect whether light passes through a slit in the radial direction of a rotating disk called a code wheel attached to the motor shaft.

- The light pulse signal changes as it passes through the slit, and the amount of rotation of the motor shaft can be detected by counting the number of pulses.

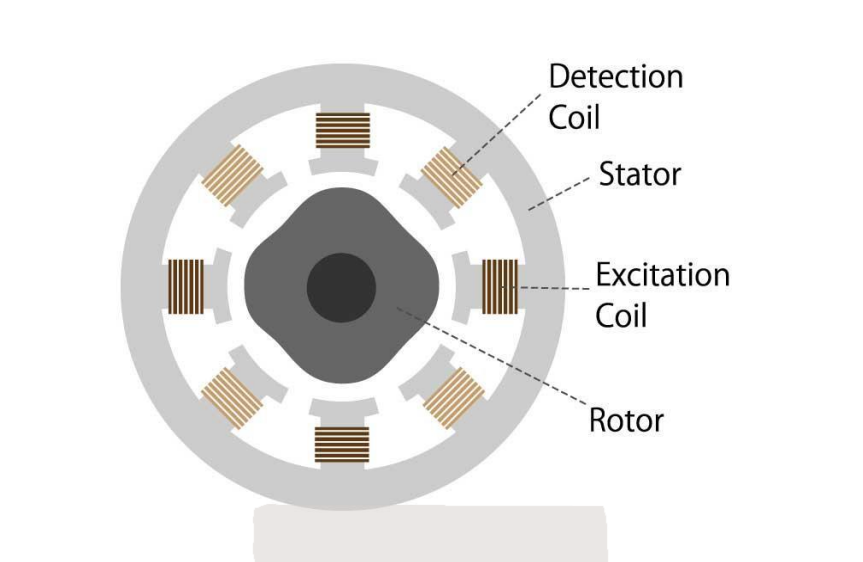
Magnetic Encoders



- This method uses a magnetic sensor to measure changes in the magnetic field distribution created by a permanent magnet attached to the motor shaft.

- When the motor shaft rotates, the magnetic field distribution of the permanent magnet also changes, so if you detect it with a magnetic sensor, you can determine the rotational position of the motor shaft.

Electromagnetic Induction Encoders



- This method reads changes in the magnetic field generated between the induction coil (excitation coil) and fixed coil (detection coil) attached to the motor shaft.
- The basic principle is the same as a transformer using electromagnetic induction, and such an encoder is called a resolver.
- The power supply to the rotating induction coil of the resolver has a risk of wear due to the contact method using a brush. However, there is a VR (Variable Resistance) resolver that improves this risk.

Applications of Position Encoders

Robotics – used for precise control of robotic arms, joints and wheels, enabling accurate positioning and movement.

CNC Machines – provide feedback for the precise control of cutting tools and workpieces.

Industrial Automation – used in conveyor systems, robotic arms and automated machinery for precise position control.

Elevators – ensure accurate stopping at each floor by providing feedback on the elevator's position.

Aerospace – used in navigation systems for accurate position feedback of control surfaces.

Medical Devices – provide precise control in devices like MRI machines and surgical robots.

Encoders in Robotics

- Robots must go just where it's supposed to (encoder accuracy) as quickly as possible (encoder resolution), whether it's an entire arm or just the tool center point.
- Most robots use servo motors to move their joints, through rotary or angle encoders.
- As speeds increase, so do the control dynamics the motors require, sometimes making vibration mitigation just as important accuracy and resolution.
- No matter the specific applications, careful encoder selection for robotics is crucial.

Pros and Cons

- The incremental method has only one or two row of slits, so the code wheel can be manufactured at low cost.
- The absolute method that represents the absolute angle, the slits are arranged in multiple rows, so if the resolution of the angle change is to be increased, the code wheel manufacturing cost will be expensive.
- If the motor is stopped and restarted after the power is turned off, the absolute method can detect the position at the time of restart. However, in the case of the incremental method, the position at the time of restart cannot be detected because the accumulated angle has been deleted.
- In the absolute method, there are: method of outputting a binary code as a digital signal and a method of converting a binary code to an analog voltage and outputting it.

Review Incremental Encoders appropriate for a SCARA Robot

- Review criteria:
  - Working principle of incremental encoders.
  - Why incremental encoders can be used for SCARA robots (applications)?
  - How incremental encoders are embedded in SCARA robots?

Interfacing with Robot Control Board

Identify the sensors and control board

Understand sensor specifications

Prepare the required components

Connect the sensors to the control board

Write the code

Test and calibrate


THANK YOU
HAVE A GREAT DAY