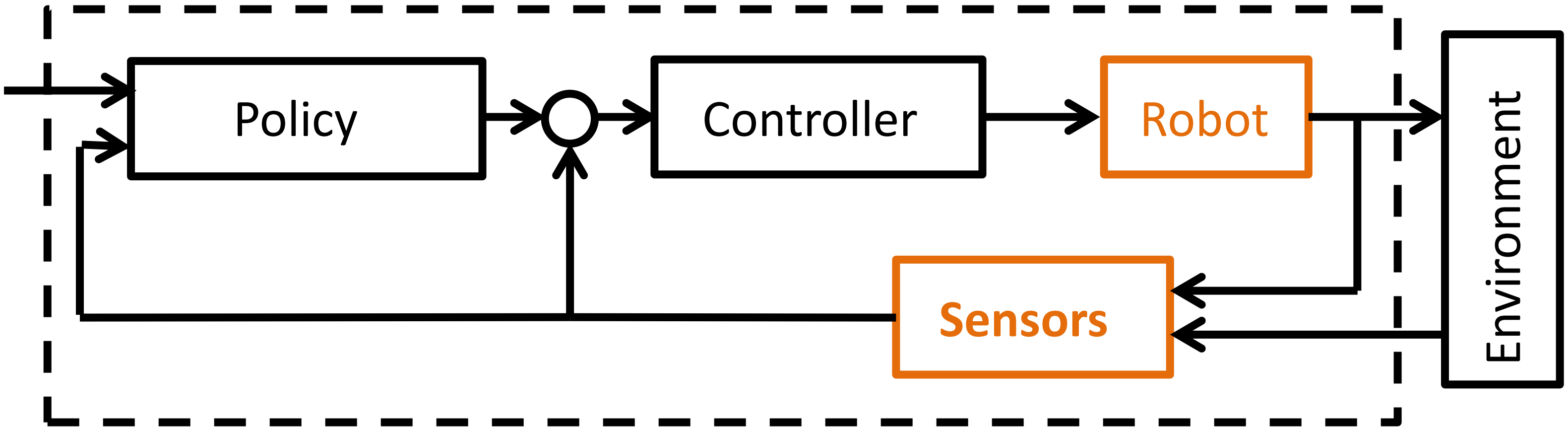
MAEG5402 Advanced Robotics

Robot Actuators and Sensors

A Typical Robotic System



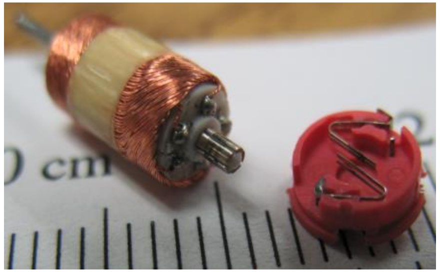
Actuators

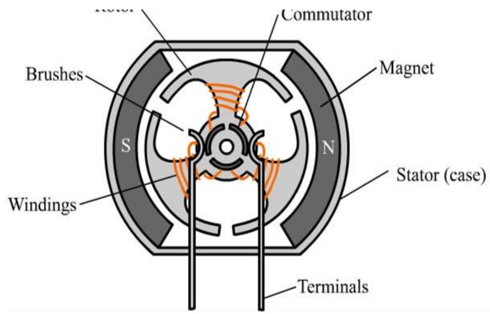
Main way to characterise based on **working principle**

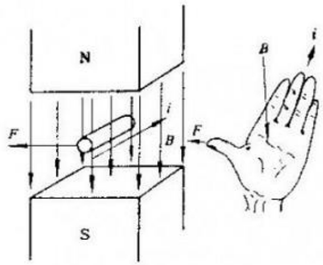
- Electric actuators
- Hydraulic actuators
- Pneumatic actuators
- Cable actuators
- Shape memory alloy
- And many more…

Electric Motors

Converts electric energy into mechanical energy







- Easy to control
- Accurate
- Fast response
- Clean
- Many different types of electric motors exist
- Low-power output compared with some other actuators

DC Servo Motors

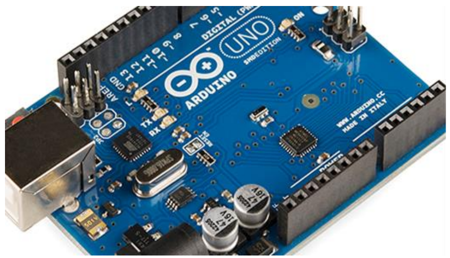
- DC servo motor
  - AC and DC (but mostly DC for robots)
  - Many types and specifications
  - Controlled using PWM
  - Control position/velocity/acceleration

Source: https://www.youtube.com/watch?v=hg3TIFIxWCo

DC Servo Motors

How motors are controlled

- Send command from microcontroller to motor controller

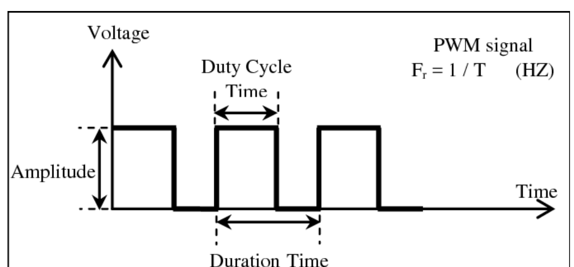


PWM

Digital signals

Accepts analogue voltage input

- PWM command is a conversion between digital and analogue

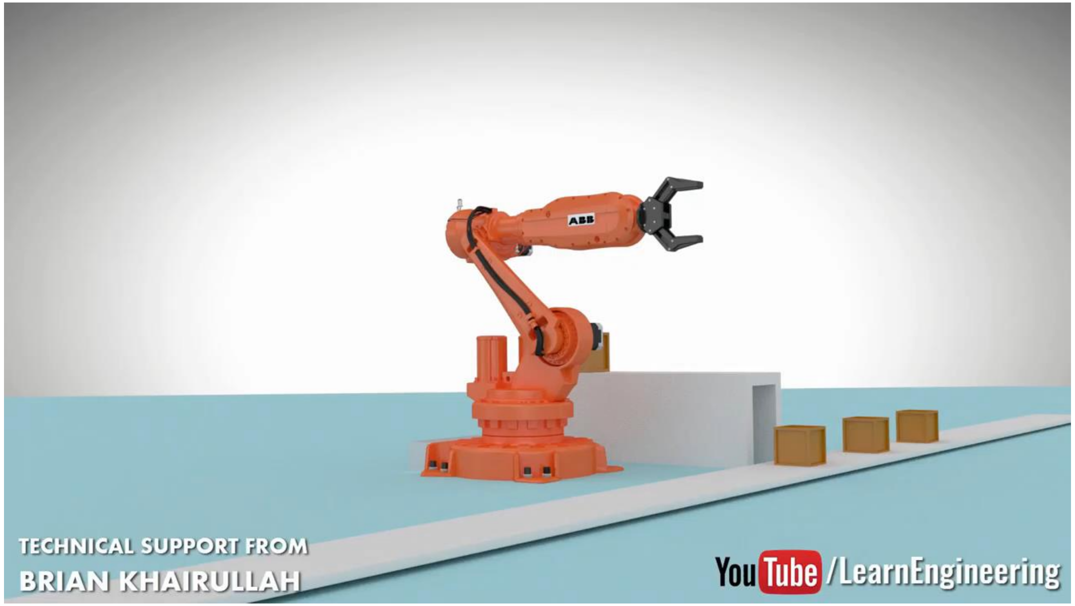


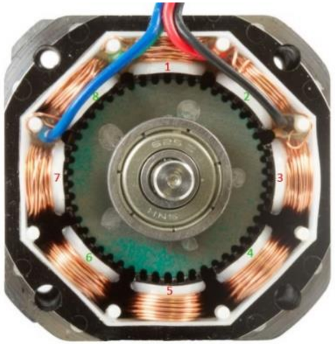
60% duty circle

DC Stepper Motors

Stepper motors are a variant of DC motors

- Focused on high position accuracy
- Weaker in torque/power





https://youtu.be/eyqwLiowZiU

RC Servo Motors

Another variant

- Simple and easy to use
- Low in cost
- Position command only (mostly)

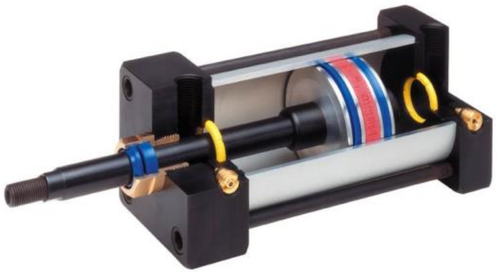
- Great for testing/prototyping
- Or lightweight applications
- And low precision requirements

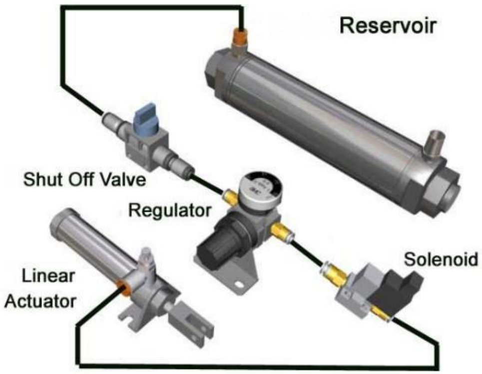
1) By oomlout - SERV-03-MI (Micro Servo), CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=19867075
2) By oomlout - Exploded Servo, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=23310692

Pneumatics

Name from Greek

- ***πνευμα*** (pneuma), means "wind, air, breath, spirit"
- Converts compressed air into mechanical motion
- Clean in using air
- Not so precise
- Good power

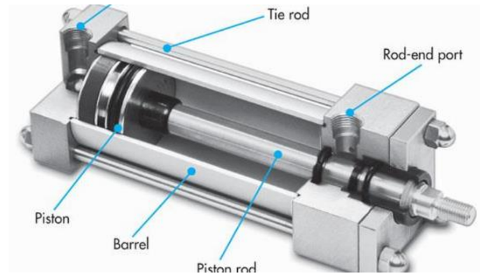


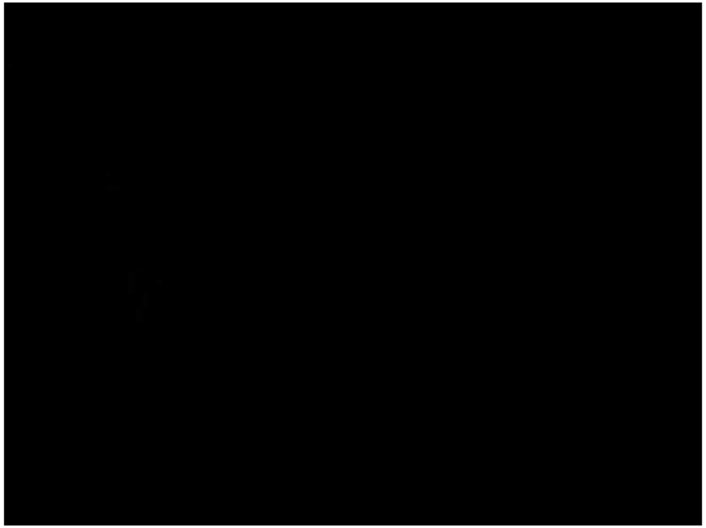


Pneumatics

Applications

- Prismatic actuators
- Muscles actuators





1) **Pneumatic Pistons: https://www.youtube.com/watch?v=Rsqc1-vjkRs**
2) **FESTO Muscle Robot: https://www.youtube.com/watch?v=2iG1ybuchx0**

Hydraulics

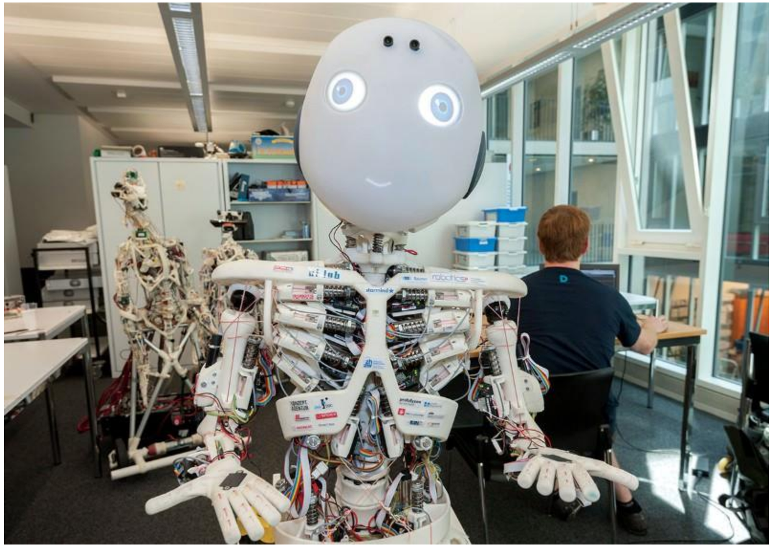
Similar to the idea of pneumatics, but using oil or fluid

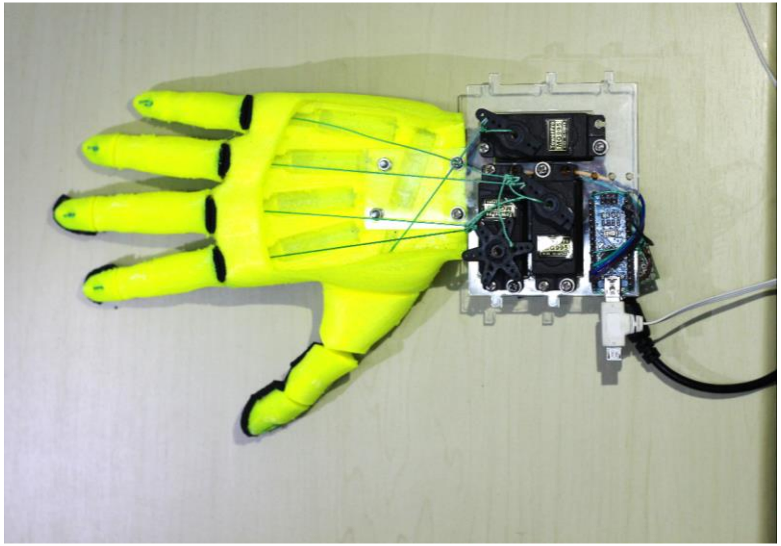
- Higher strength and more smooth
- The liquid can be very messy
- Typically larger/heavier

Cable-Drive

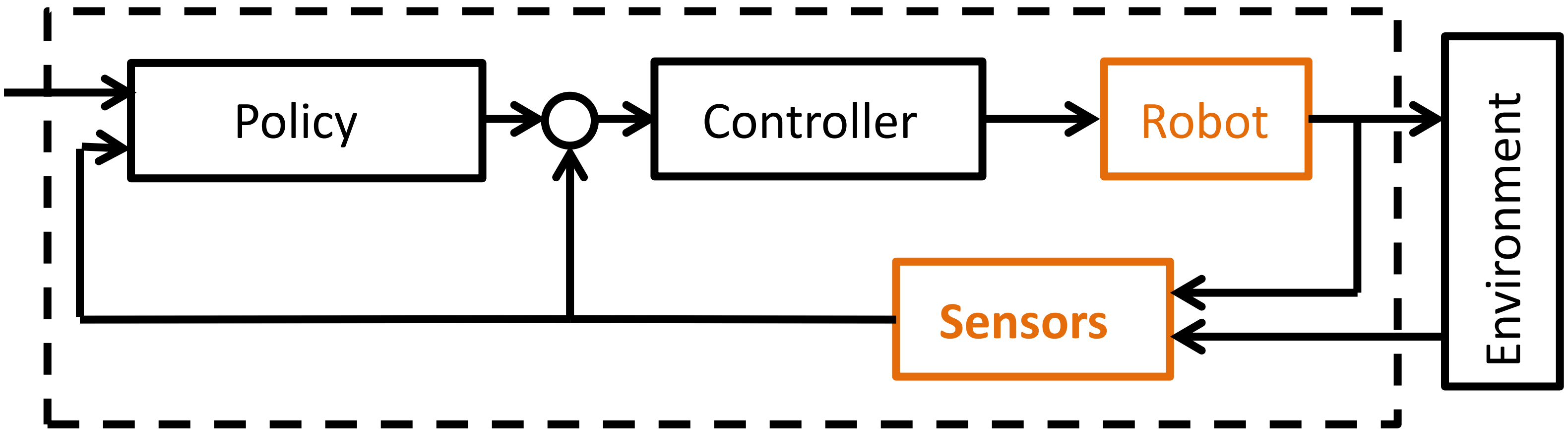
Use cables to relocate the location of motors

- Large distance
- Lightweight system
- Place motors at more desirable locations
- Simple dynamics

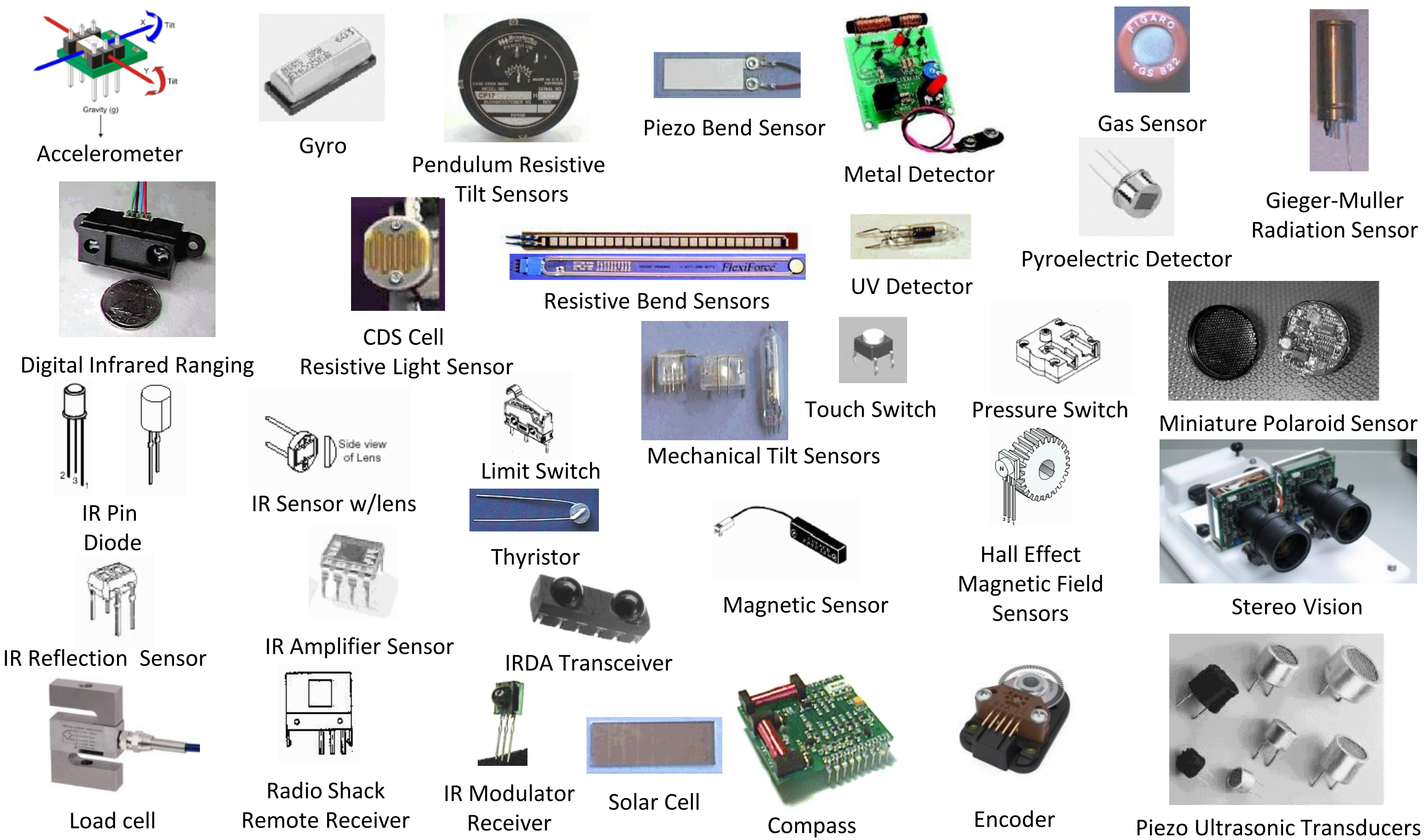




Parts of a Robotic System

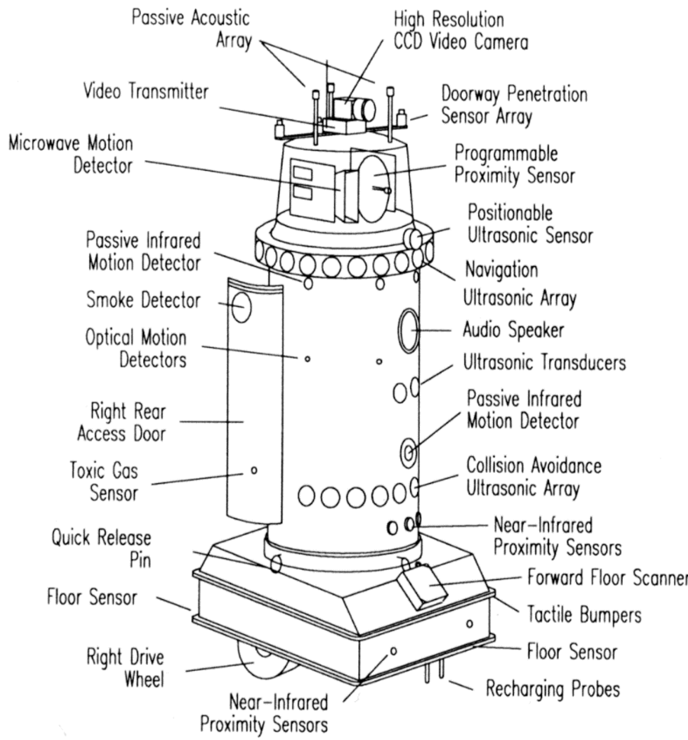


Types of Sensors



Sensors in Robots

Must-have component in robots



Robart II (H. R. Everett)

PeopleBot (Activmedia Robotics)

Classifications of Sensors

Internal sensors (proprioceptive)

– Obtain information about the system itself

External sensors (exteroceptive)

– Obtain information about the environment

Passive sensors

– Energy/excitation coming from the external environment

Active sensors

– Energy/excitation coming from the sensor

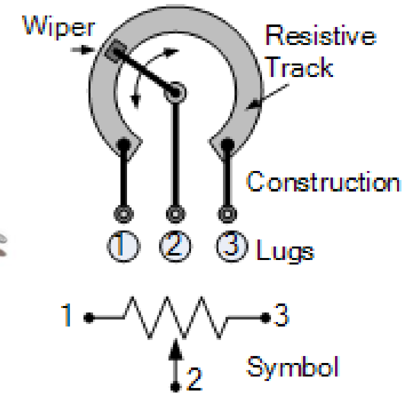
Angle sensors

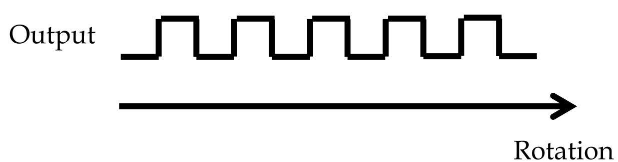
Rotation is very common (since motors rotate)

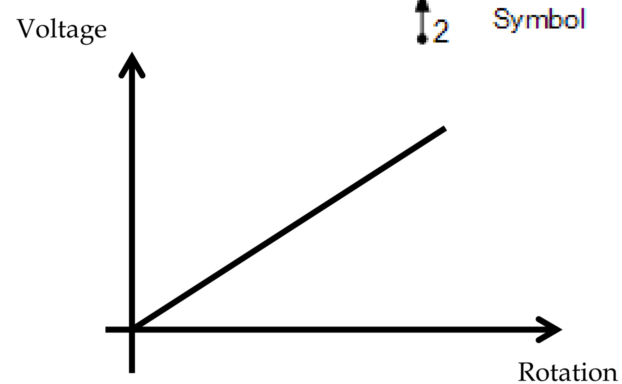
– Encoders and potentiometers

Maxon motor encoder

Linear optical encoder



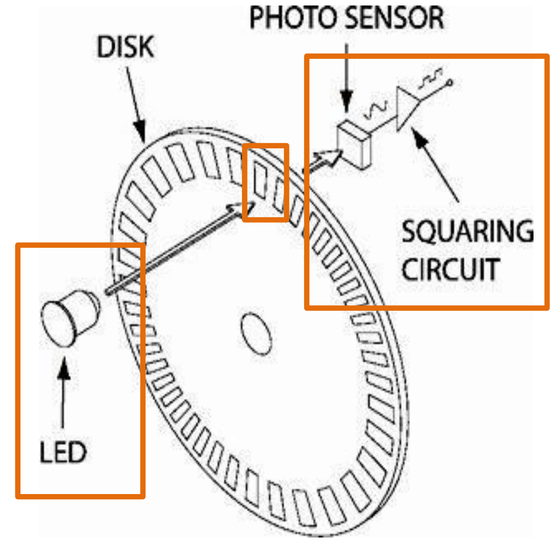




Optical Encoder

How does it work?

- LED is a light transmitter
- Photosensor detects if light is received
- The disk with holes allows light through

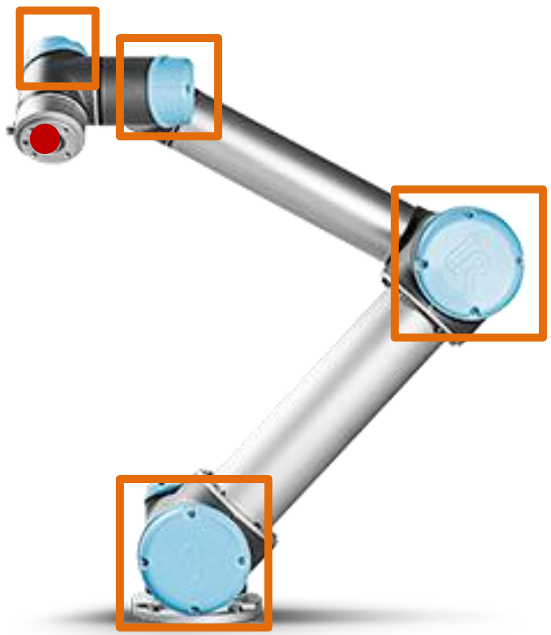


Classification

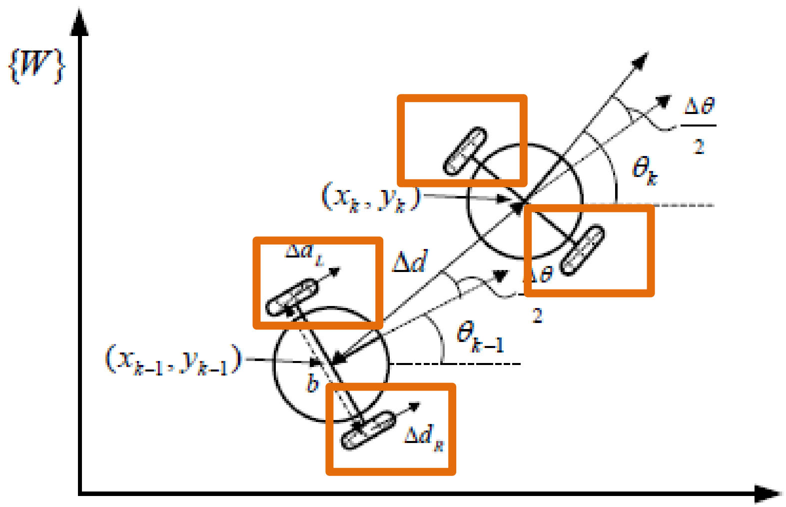
- **Proprioceptive sensor** since it measures internal rotational or translational motion of the robot (not the environment)
- **Active sensor** since sensor sends light to be received

Optical Encoder

- Applications

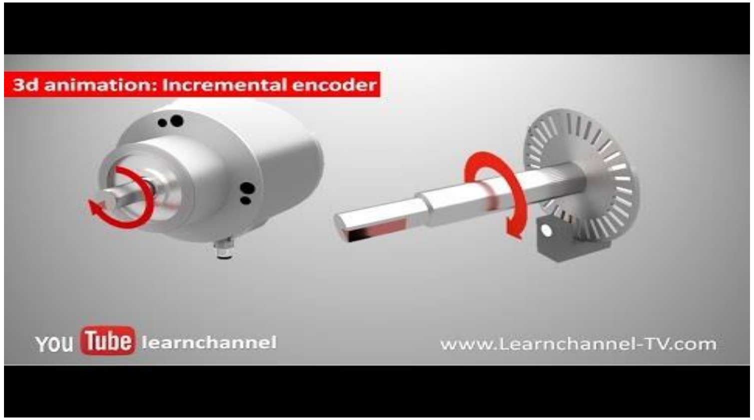


Robot joints to end-effector position



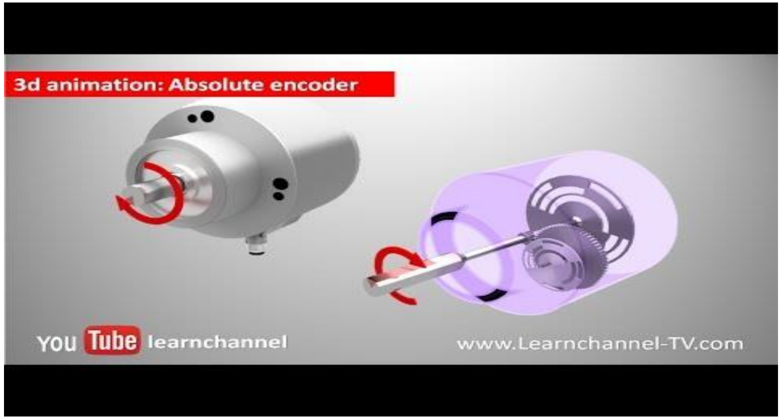
Robot wheels to robot position (dead reckoning)

Video illustration



Incremental Encoder

https://youtu.be/zzHcsJDV3_o

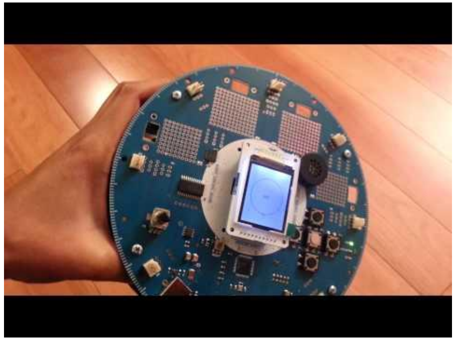


Absolute Encoder

https://youtu.be/yOmYCh_i_JI

Orientation Sensors: Compass

- Measures the heading (orientation and inclination)
  - By using the earth's magnetic field field



- Dead-reckoning
  - Determine the future position by using the orientation with velocity information then integrate
- Drawbacks
  - Weakness of the earth's magnetic field
  - Easily disturbed by other sources (magnetic)
  - Not feasible for indoor environments

Orientation Sensors: Gyroscopes

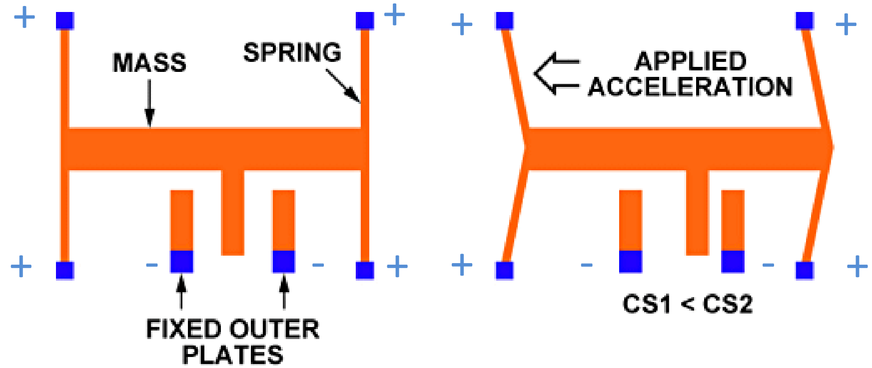
- Gyroscopes are now used in many places
  - A gyroscope is a device used for measuring or maintaining orientation and angular velocity.
  - Planes, multi-copters, segways, and smart phones and gadgets

- Measures orientation based on the principle of
  - A body in motion stays in motion unless it's acted upon by an external force
  - Measures this to know the motion

- Examples of two types
  - Mechanical gyroscopes
  - MEMs gyroscopes

Translation Sensors: Accelerometer

- As the name suggests
  - The sensor measures the linear acceleration in different directions

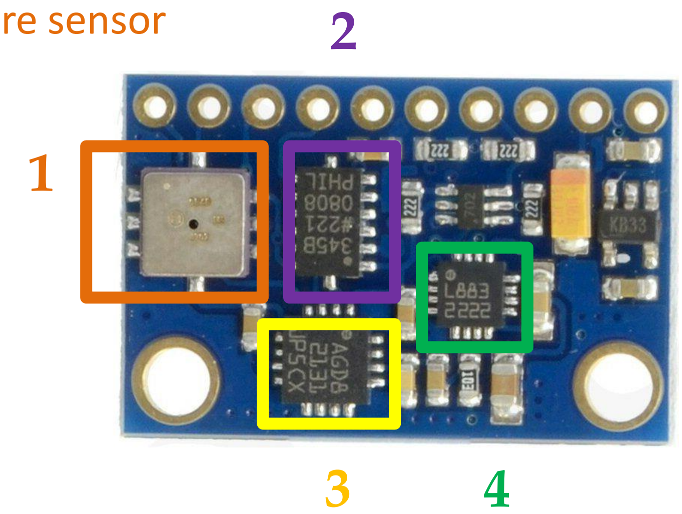


- MEMs (microelectromechanical) accelerometers
  - When acceleration in a particular direction occurs, the mass moves and changes the capacitance of the fixed outer plates

Inertial-Measurement Units (IMUs)

- A combination of sensors to measure the "inertia"
  - Typically contains at least 3-axis accelerometers and 3-axis gyroscopes to provide 6 degrees of freedom (DoF) information

- Example GY-80
  1. Barometric pressure and temperature sensor
  2. 3-axis accelerometer
  3. 3-axis gyroscope
  4. 3-axis digital compass



- Extremely useful in robotics

Translation Sensors: Accelerometer

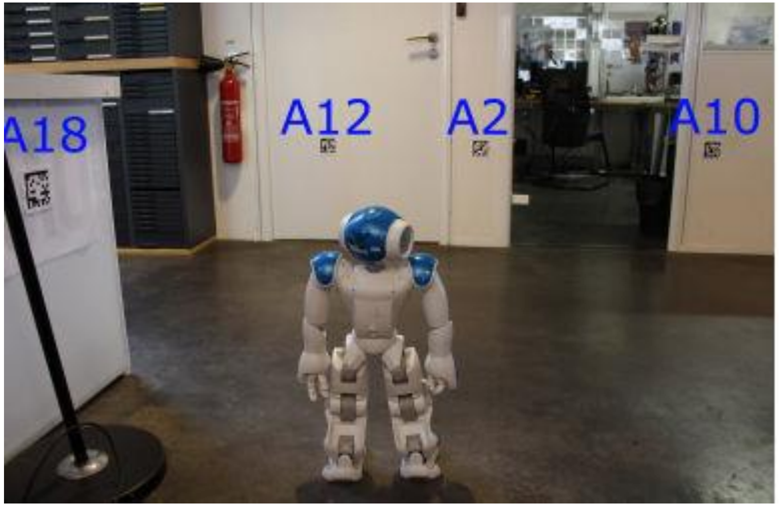
- How it works?

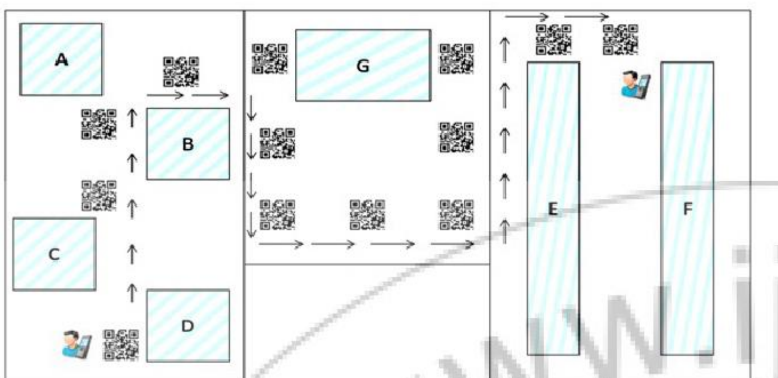
https://www.youtube.com/watch?v=eqZgxR6eRjo

Vicon System

- Opposite to ground beacons, same principle

QR Tags



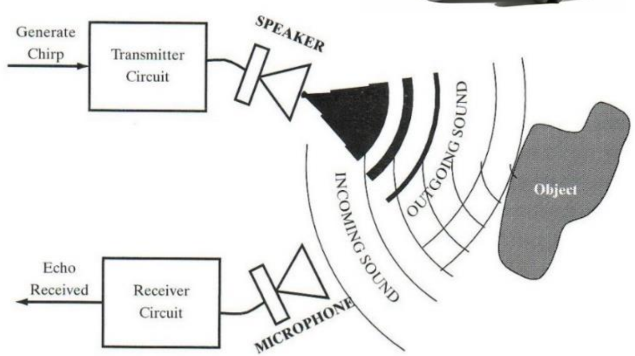


http://wiki.ros.org/visp_auto_tracker

Range Sensors: Ultrasonic Sensors

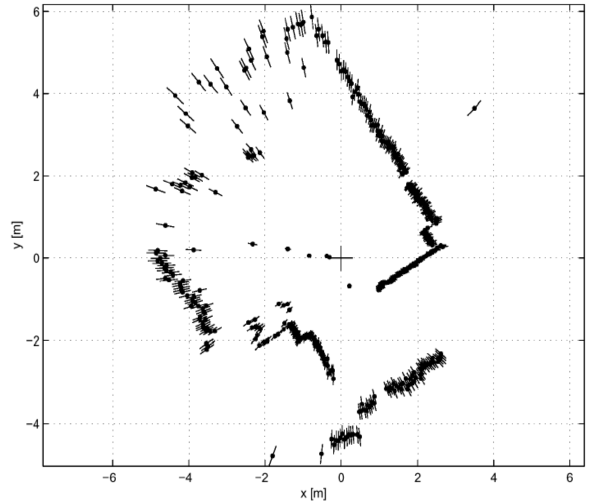
- Sends a ultrasonic wave and waits for the rebound
  1. Emit a quick burst of ultrasound (40 - 180kHz)
  2. Measure the elapsed time until the receiver indicates that an echo is detected.
  3. Determine how far away the nearest object is from the sensor

- Large range distance measurement
  - Also used heavily for obstacle avoidance
  - Delay is a problem



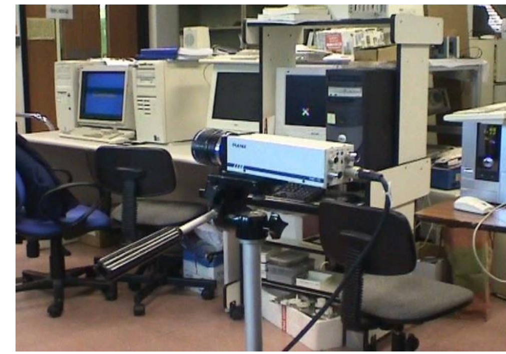
Range Sensors: Laser Range Finder

- Working principle
  - Same as that of the ultrasonic sensor, except uses **light** instead
- Much faster than ultrasonic sensor
  - For 3m distance, it takes about 10 milliseconds for an ultrasonic system but only **10 nanoseconds** (speed of light vs sound)
- Issues
  - Inaccuracies in the time of flight
  - Variation in propagation speed
  - These result in uncertainties



Vision

- Vision is very difficult and also very important in robotics
  - Geometric information
  - Texture
  - Color
  - Etc.

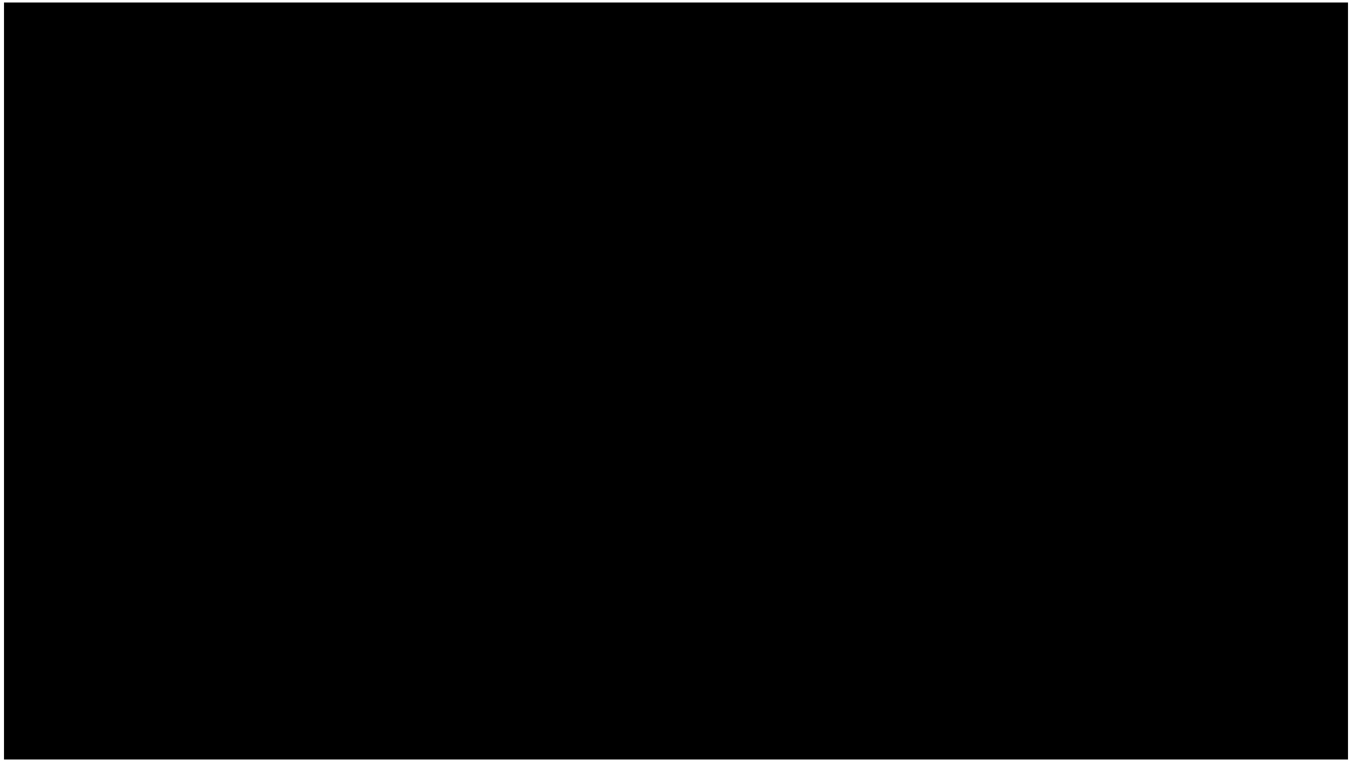


- Many applications in robotics
  - Distance measurement
  - Object/person recognition
  - Control

- Vision systems
  - Single camera, stereo camera
  - Active vision, passive vision

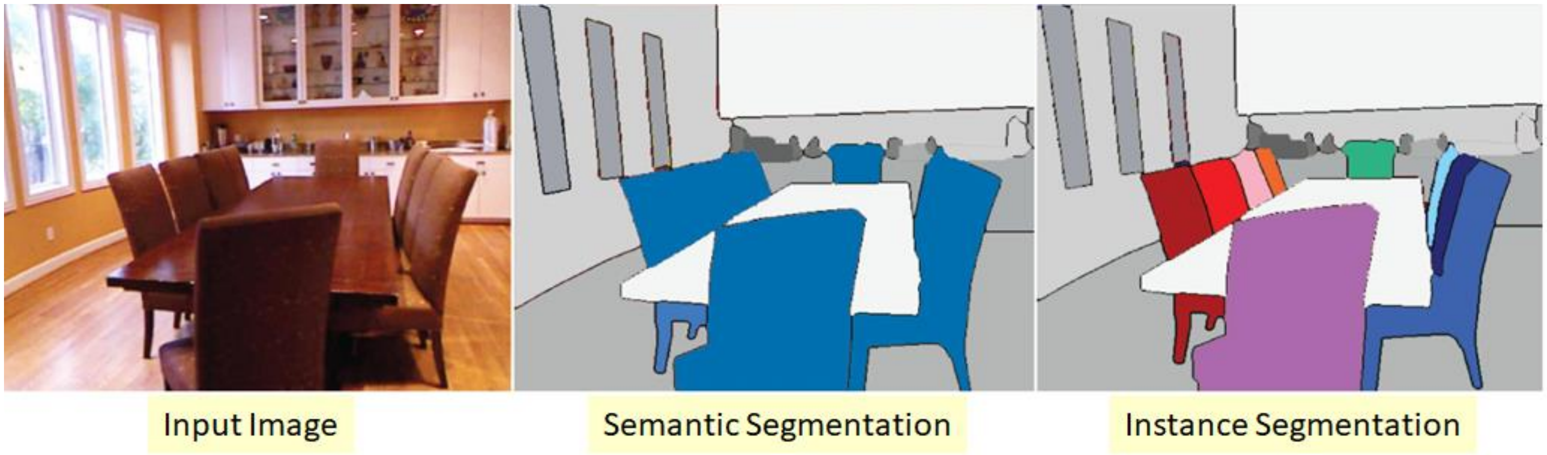
Vision and Kinect (RGB-D)

- **R**ed **G**reen **B**lue **D**epth



Vision Difficulties: Segmentation

- Partition an image into multiple segments



Vision Difficulties: Classification

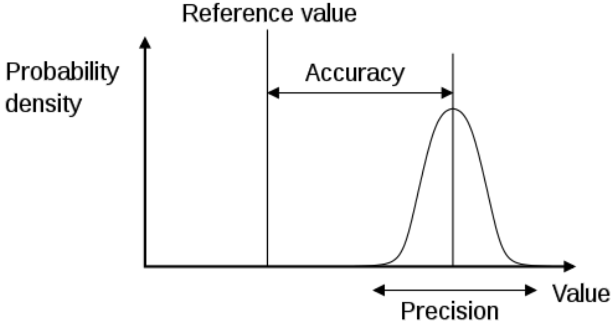
- The same “object” may look quite different

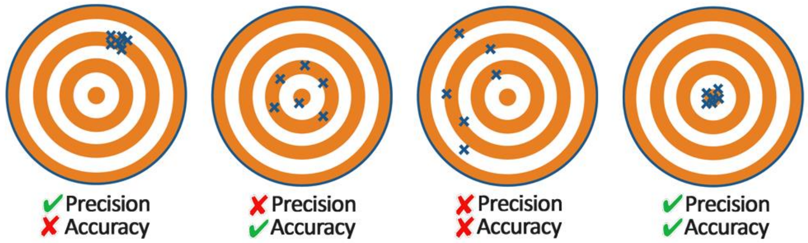
Real Sensors: Accuracy and Precision

- **Accuracy**
  - Difference between the measured value and true value

$$e = v_{measured} - v_{true}$$

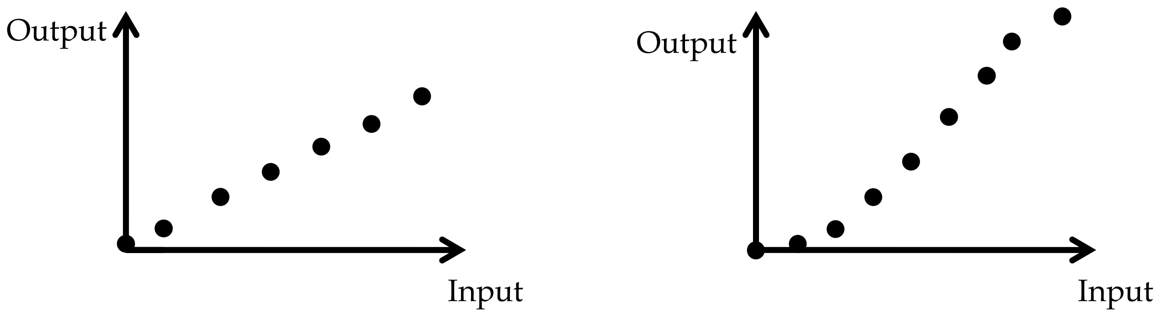
- **Precision**
  - Repeatability of measurement





Real Sensor Properties: Linearity

- **Linearity**
  - Many sensors have (or desired to have) a linear relationship



  - The relationship between input and output is important

Real Sensor Properties: Resolution

- **Resolution**
  - Smallest change in input **that could be detected**
  - Units is the same as the input

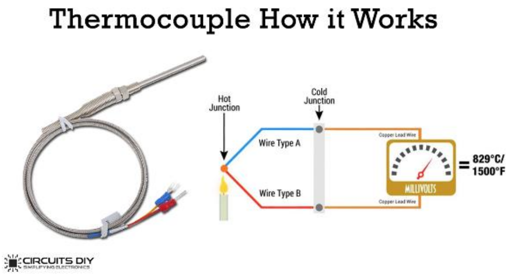
- For the joints of the robot arm
  - The smallest change in angle **that could be detected**

$$R = \frac{\Delta \text{input}}{\Delta \text{output}}$$

Real Sensor Properties: Sensitivity

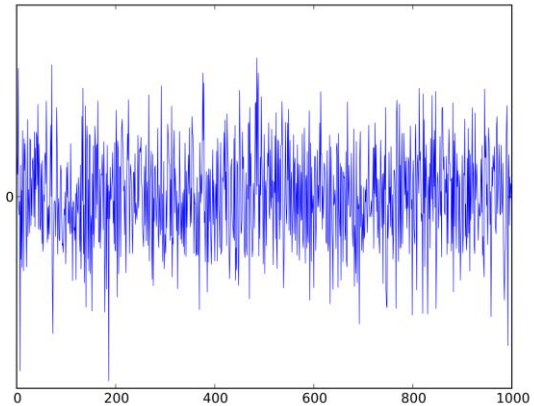
- **Sensitivity**
  - Relationship between input and output if not the same units
  - The amount of output for unit input

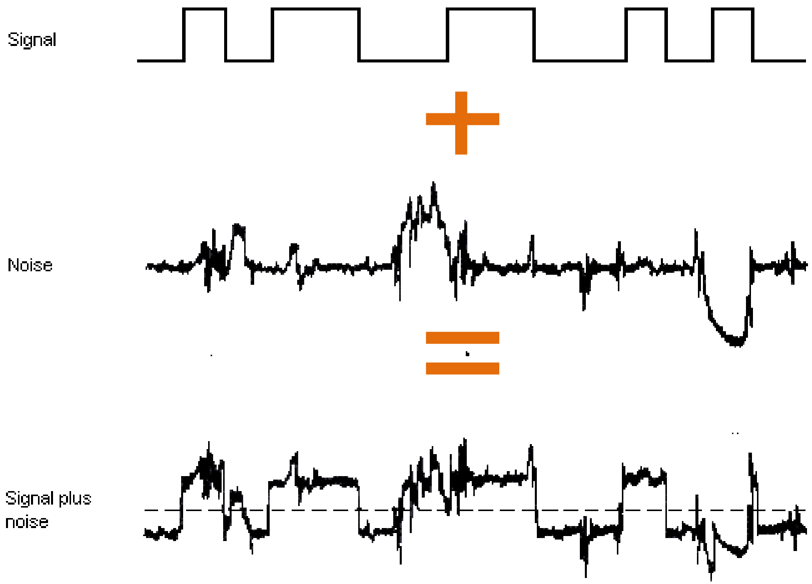
- What is the difference between resolution and sensitivity?
  - For a "thermocouple":
  - Sensitivity may be uV/C (microvolt per Celsius degree)
  - Resolution is the minimum degree that can be detected



Real Sensor Properties: Noise

- **Noise**
  - In addition to issues such as precision or drift, noise also plagues the transmission of signals

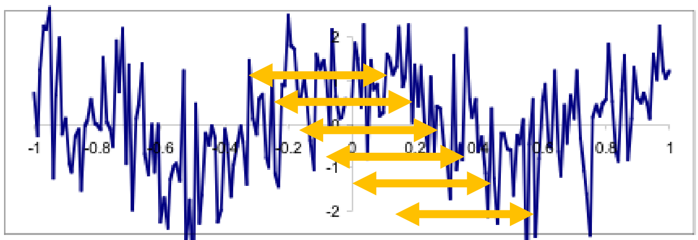




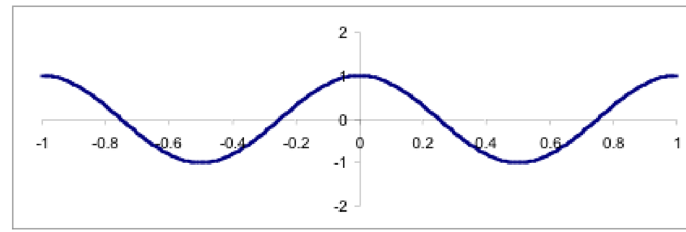
  - How to remove noise from a signal is an important and big topic

Real Sensor Properties

- **De-noising or filtering**
  – A process to make noisy signal cleaner to use



(b)



(a)

  – Many different techniques to de-noise
- Moving average filter
  – At instance *k* with a window of *N* samples

$$x_k = \frac{1}{N}\sum_{i=0}^{N-1} x_{k-i}$$

Sensors in Robotics

- Selecting the right type depending on the application
  - E.g. position sensor, force sensor, camera?
  - That requires knowledge on the **different types of sensors**
- **Calibration** of sensors
  - E.g. calibrating the zero and sensitivity of the load cell
- **Integrating** the sensors into a system
  - A combination of mechanical design, electronics and software
- Understanding and handling the **artefacts** of the sensor
  - No sensor is perfect and will suffer from artefacts
  - The artefacts are also design and sensor dependent

Calibration of Sensors

- **Calibration**
  1. Forming the relationship between the input and output
  2. Correcting any imperfections on the sensor relationship

- This is because
  – Relationship from “manufacturer” usually deviates from reality
  – Allows the “absolute” value of the angle to be determined

- Therefore it’s important to calibrate for your particular sensor

Sensor Modules

- Breakout boards for maker space:
  - SparkFun, Adafruit
  - Often comes with Arduino example code, ease of use at prototyping stage
  - For those who are into programming, an LCD monitor may be handy for debug

Interfacing with Sensors

- Common Protocols:
  I2C, SPI, UART, RS232, RS485, CAN
  ADC for voltages levels
- Arduino Libraries
  - Exist for popular sensors
  - Further explained next chapter!
- Reading through the datasheet
  - Operating voltages
  - Operating range
  - Accuracy, precision, linearity
  - Refresh rates, etc.

e.g. Range spec. for VL6180X distance sensor

Max range vs. ambient light level

The data shown in this section is worst case data **for reference only.**

Table 19 shows the worst case maximum range achievable under different ambient light conditions

Table 19. Worst case max range vs. ambient 0 to 100mm(1)(2)

Target reflectance	In the dark(3)	Worst case indoor light (1 kLux diffuse halogen)	High ambient light (5 kLux diffuse halogen)	Unit
3%	> 100	> 80	> 40	mm
5%	> 100	> 90	> 45	mm
17%	> 100	> 100	> 60	mm
88%	> 100	> 100	> 70	mm

Q&A