ISDN2400 Physical Prototyping

Electronics Prototyping

By Rob Scharff

March 2025

Today's Lecture

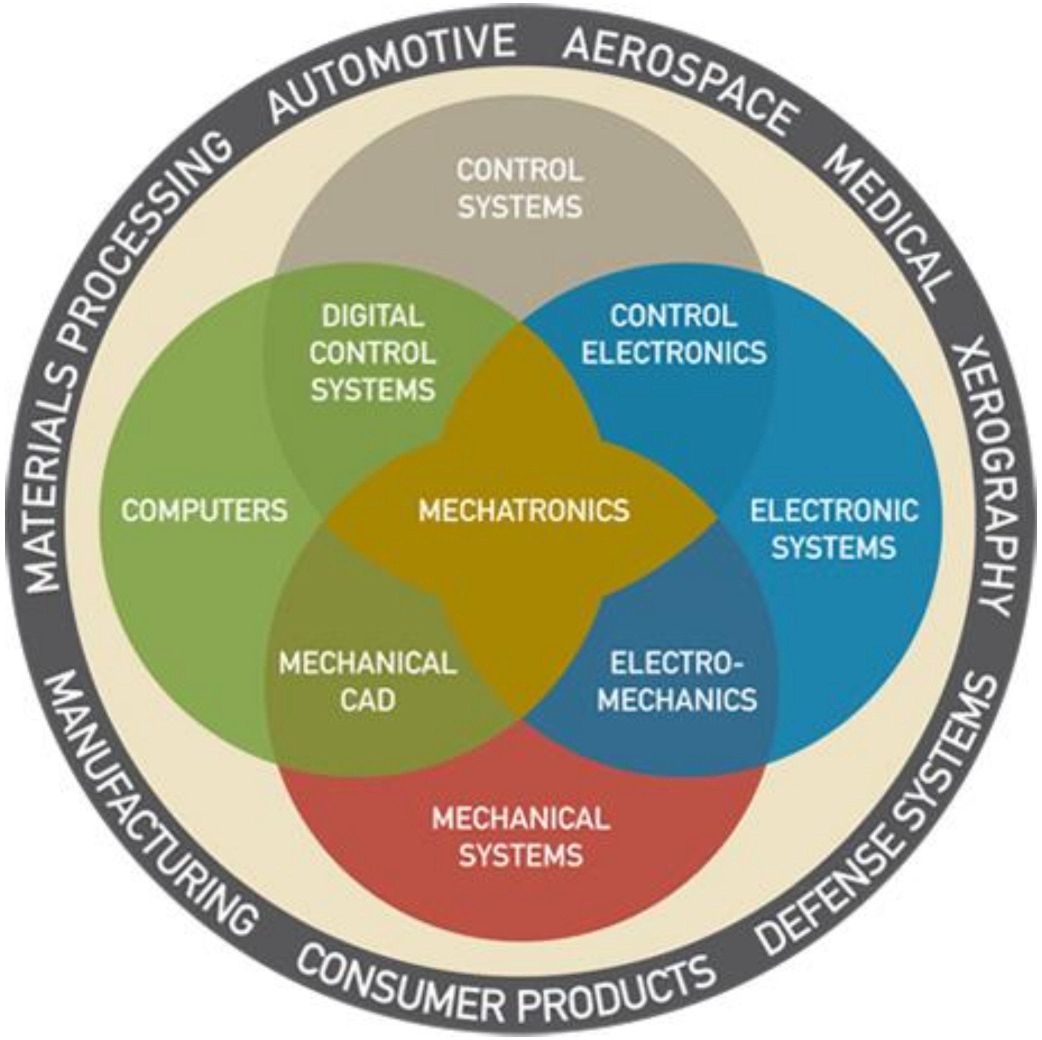
- Introduction to mechatronic systems
- Electronics prototyping
  - Sensors
  - Actuators
  - Computers
  - Communication
- Time for group work

So far…

- You learned how to prototype parts using additive, subtractive, and formative manufacturing
- However, at ISD, we often want to build mechatronic systems
  - Consumer electronics
  - Robotics
  - Transportation
  - Medical instruments

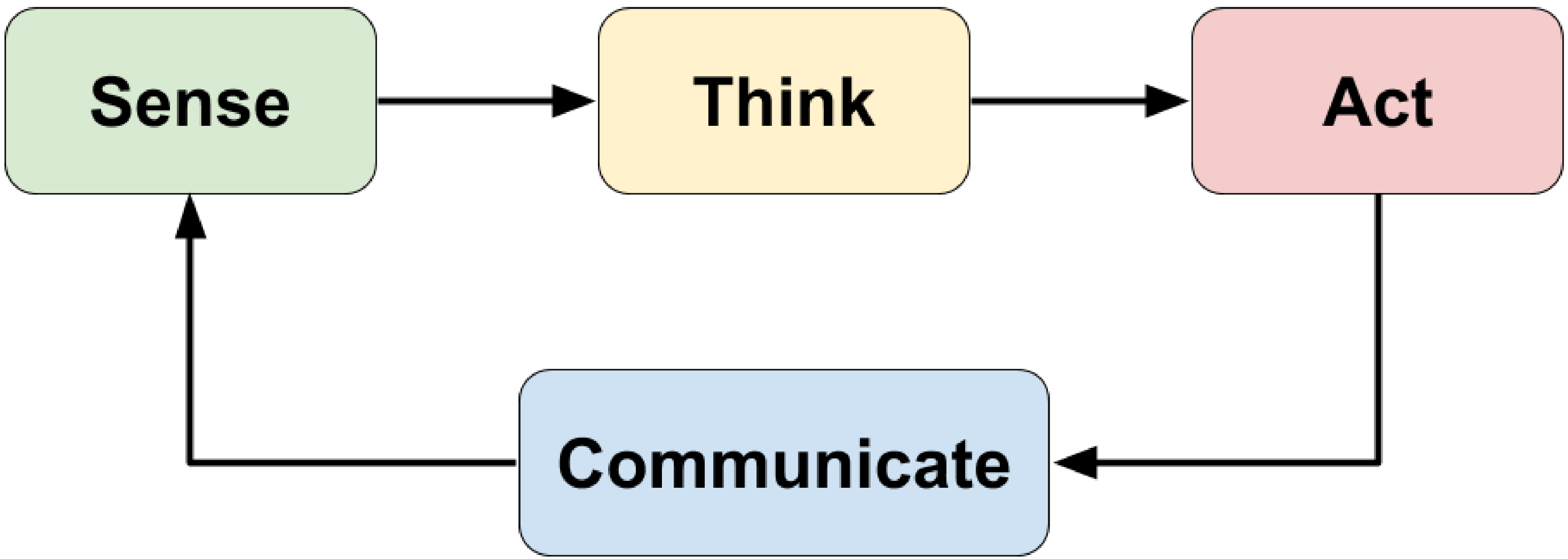
Mechatronic systems

- Mechatronics: where mechanical, electronic, control, and software engineering meet



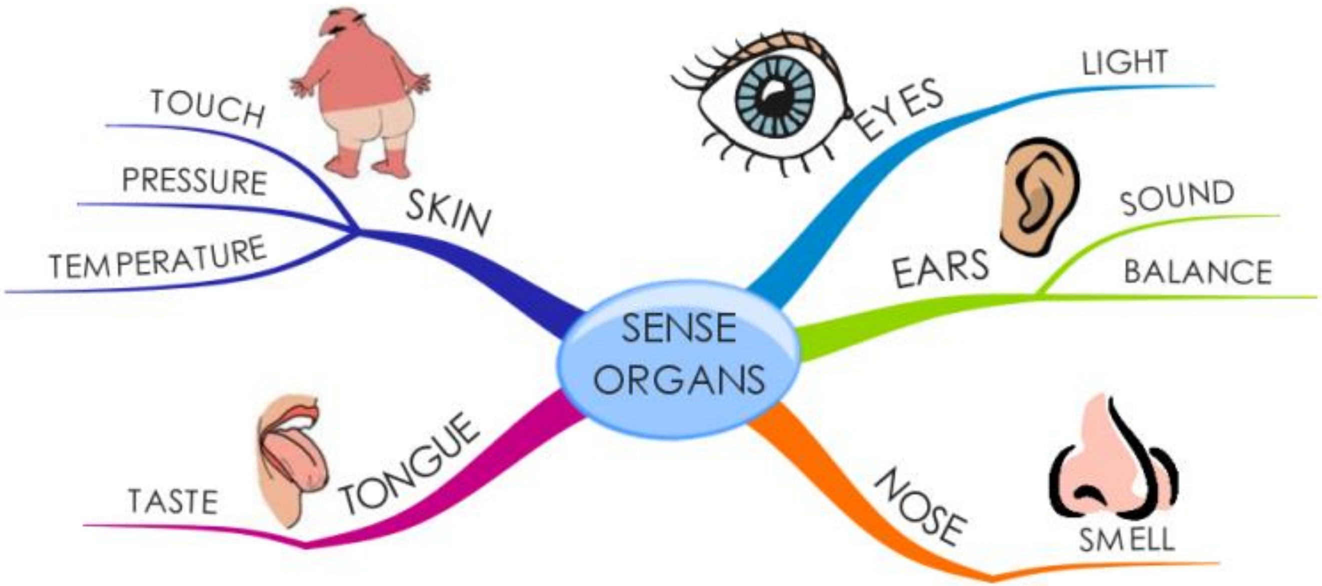
www.asme.org/topics-resources/content/mechatronics-and-the-role-of-engineers

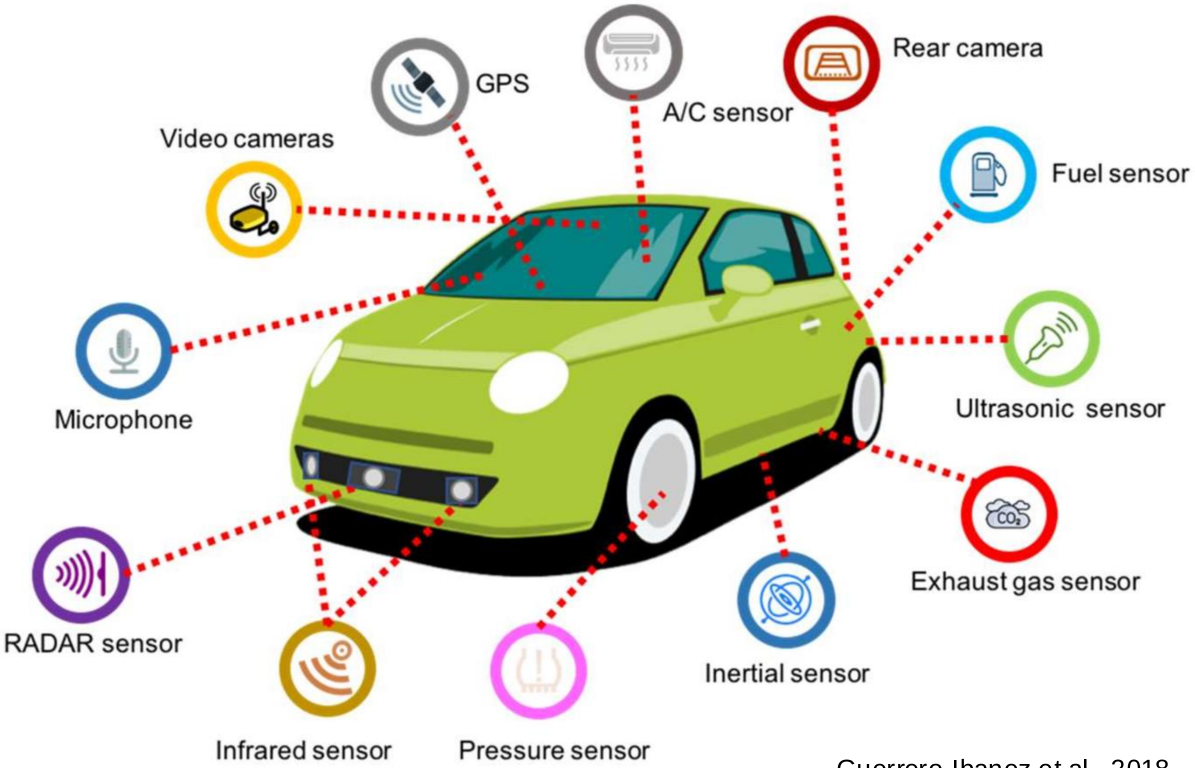
Four essential functionalities of humans, robots, and mechatronic systems?



www.docs.idew.org/project-internet-of-things/project-instructions/2-design-and-build-solution/2.2-system-model

Sensing



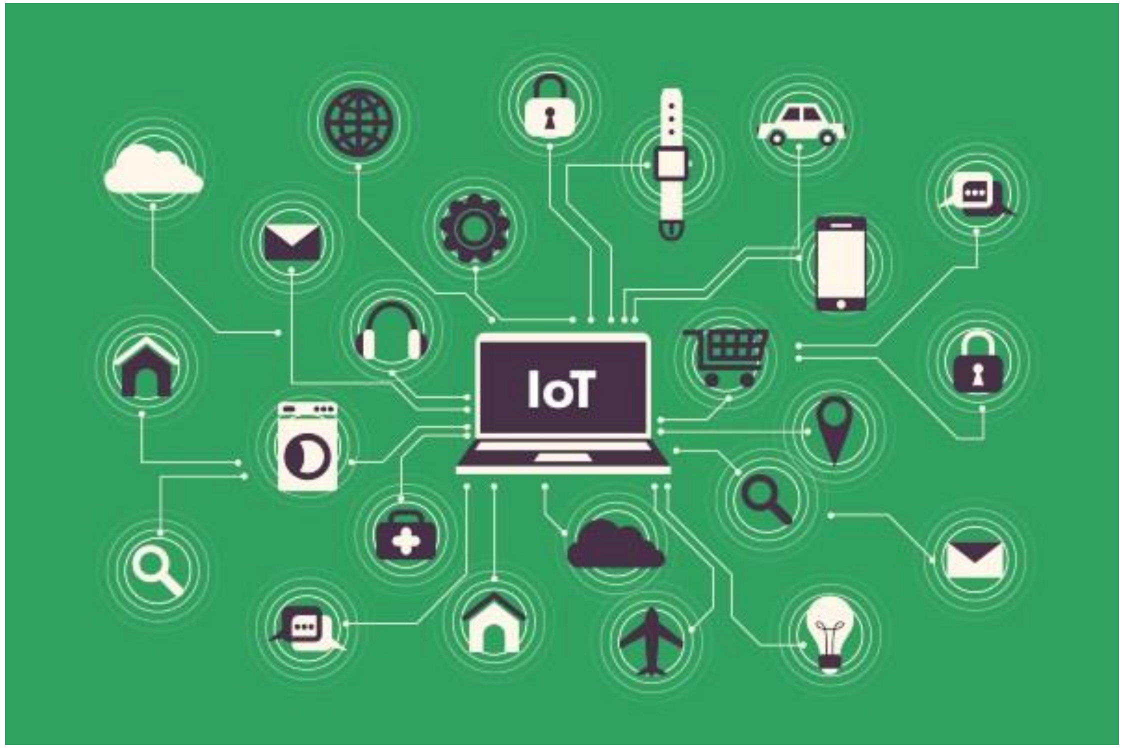


Guerrero-Ibanez et al., 2018

Actuation

Computation

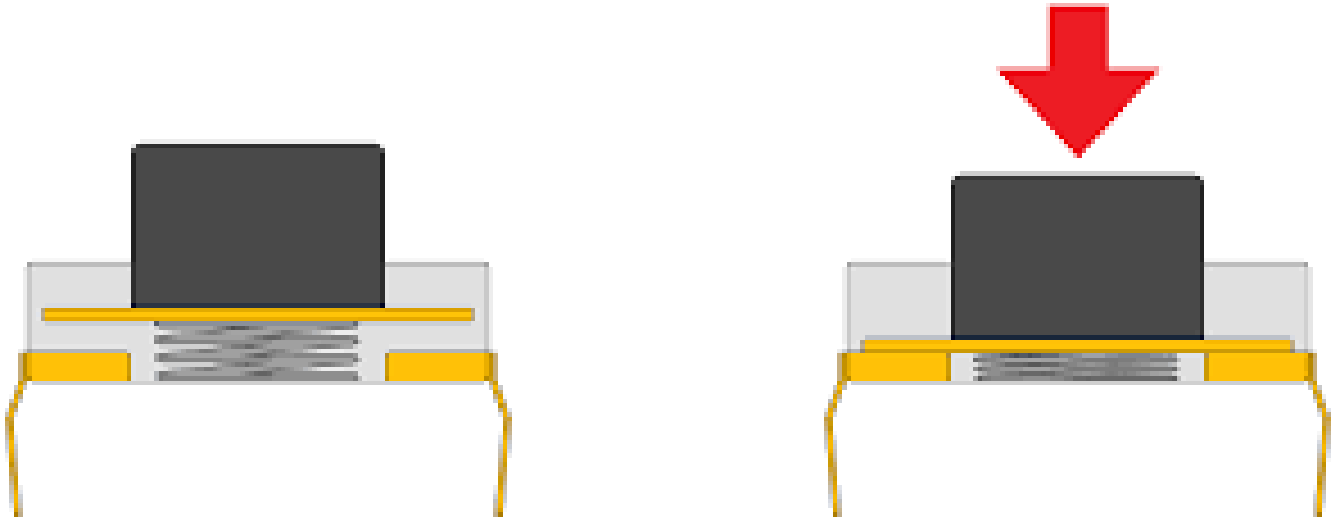
Communication



Sensors

"A device which detects or measures a physical property and records, indicates, or otherwise responds to it"

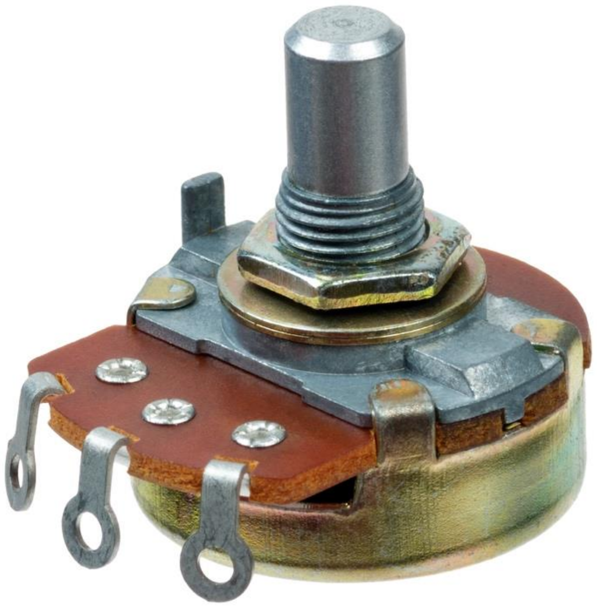
Switch/Button

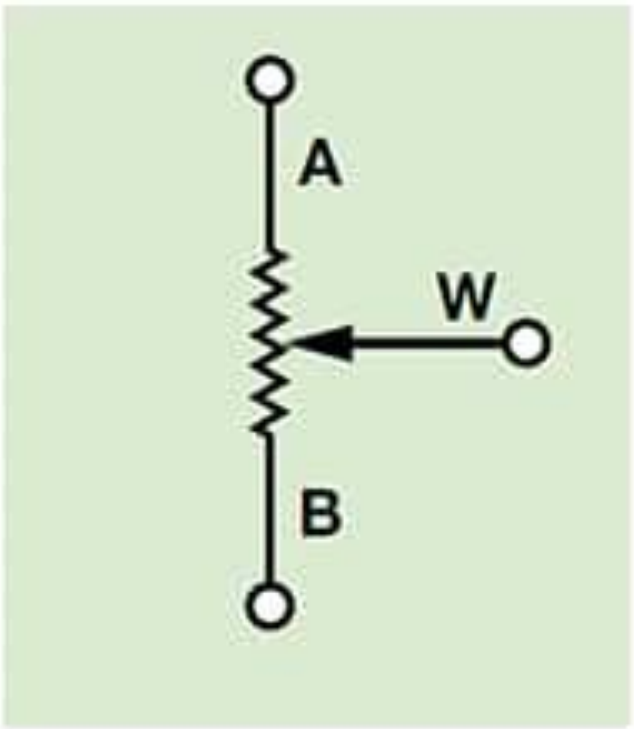


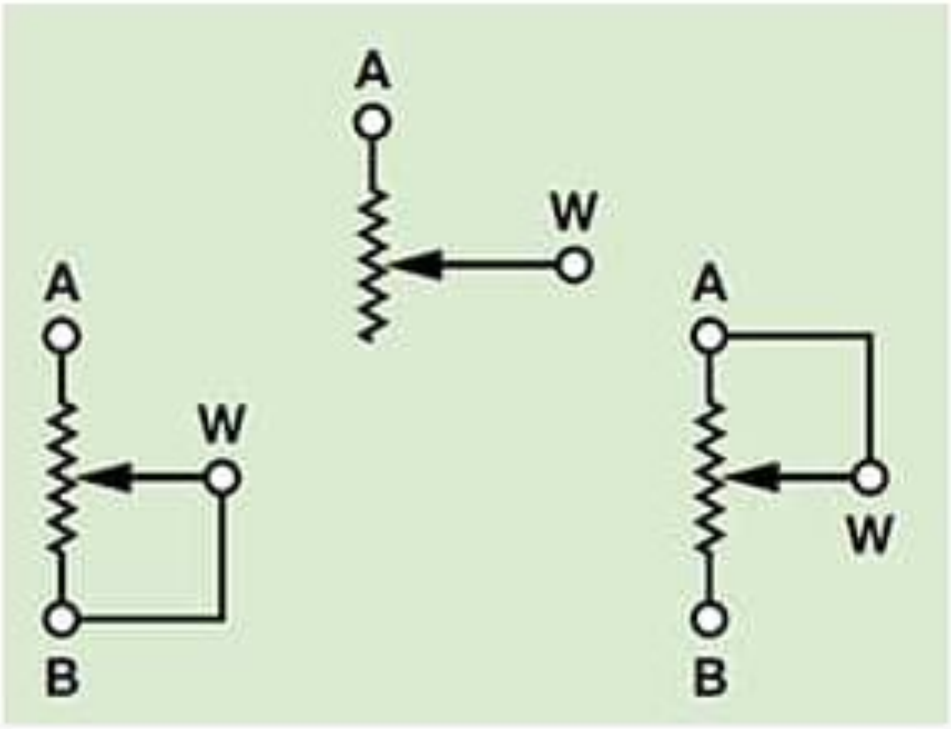
www.circuitbasics.com/how-to-connect-and-program-push-buttons-on-the-arduino/

Potentiometer

- Potentiometer: voltage divider, three terminals
- Rheostat: variable resistor, two terminals



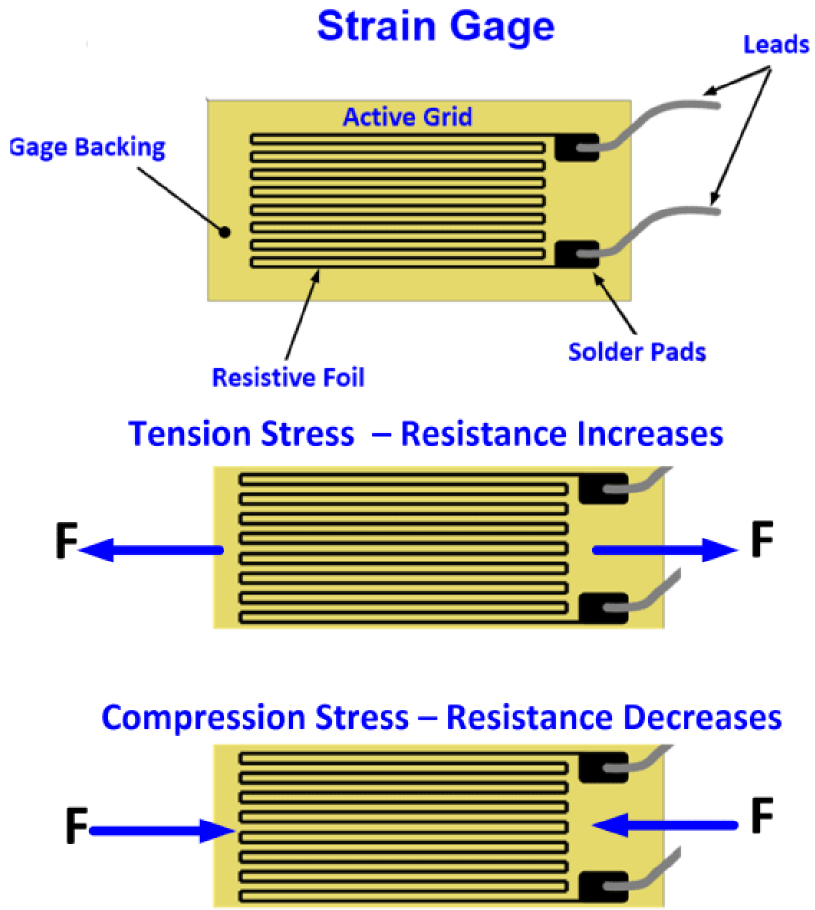




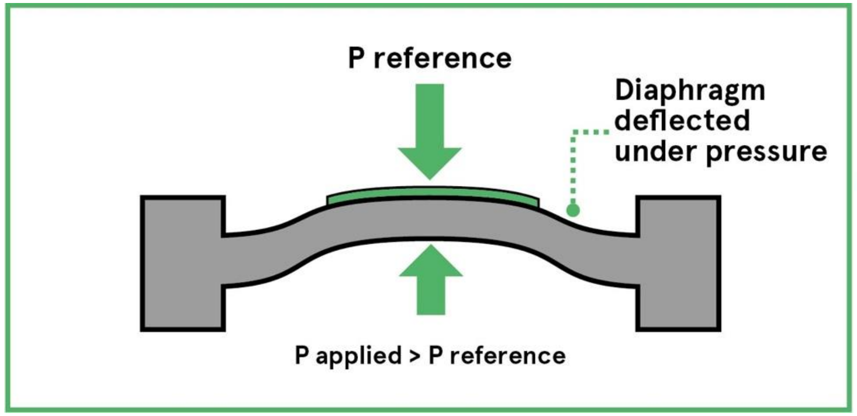
www.digikey.com/en/articles/the-fundamentals-of-digital-potentiometers

Force sensor

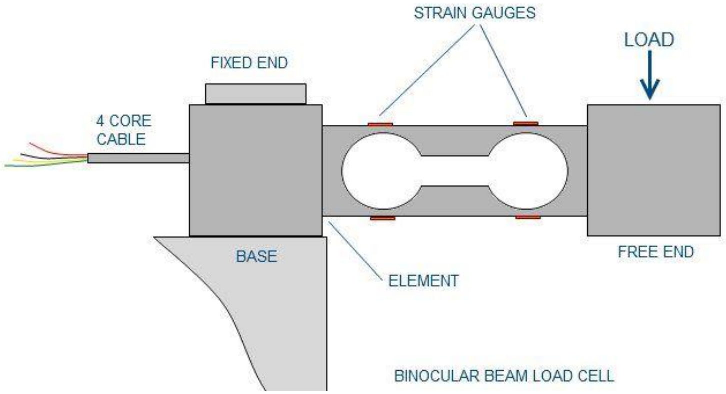
- Strain gage
  - Conductive channels become longer and narrower upon stretching
  - Resistance varies with applied force
- Can be used to create air pressure sensors or force sensors



www.digikey.com/en/articles/the-fundamentals-of-digital-potentiometers



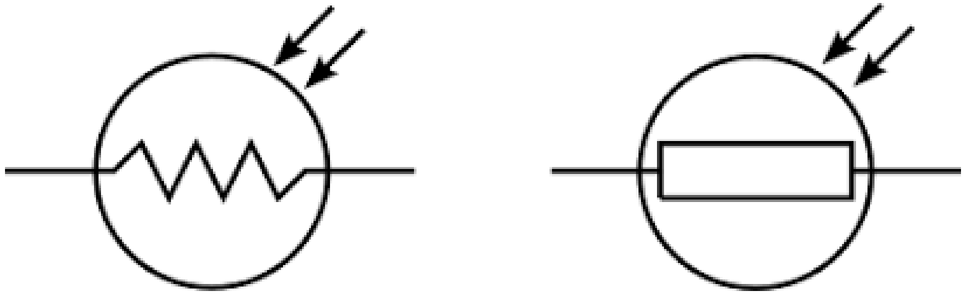
my.avnet.com/abacus/solutions/technologies/sensors/pressure-sensors/media-types/air/

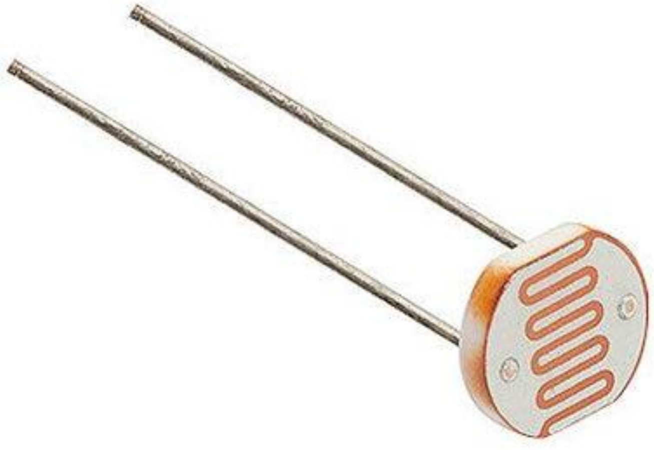


https://kobastar.com/en/how-does-a-load-cell-work/

Light sensors

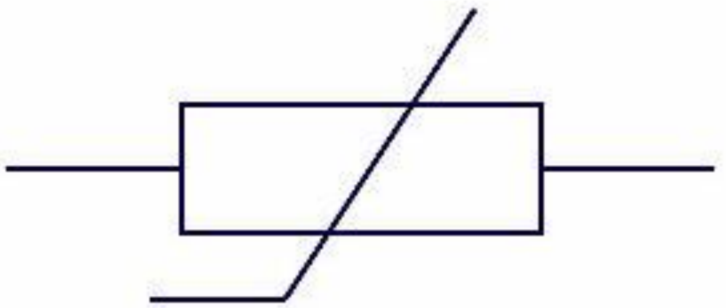
- Light Dependent Resistor (LDR)/Photoresistor
  - Very low response time
- Photodiode
  - Produces a current
  - Faster response time
- Phototransistor
  - current amplification
  - more sensitive than photodiode
  - lower response time than photodiode
- Photodarlington
  - more current amplification
  - more sensitive than phototransistor
  - lower response time than phototransistor (but still much faster than an LDR)





Temperature sensors

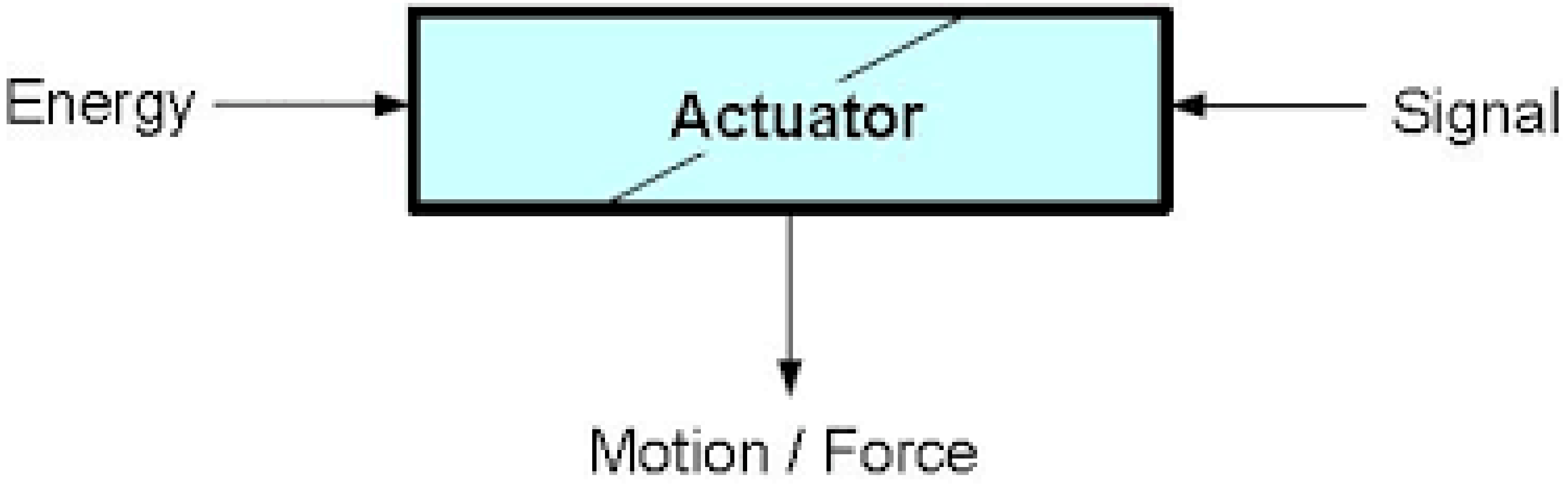
- Thermistors
- Negative Temperature Coefficient (NTC)
  - Resistance decreases with an increase of temperature



Thermistor Symbol

Actuators

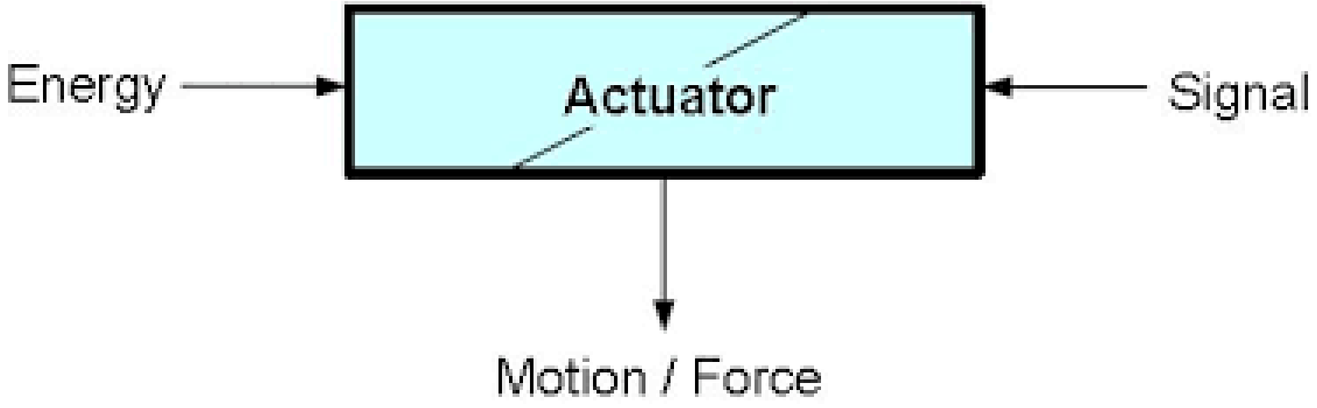
A device that converts energy to mechanical action in such a way that it can be controlled



www.standoutpublishing.com/g/Actuator.html

Types of actuators

- Energy type
  - Electric
  - Pneumatic
  - Hydraulic
  - Thermal
- Motion type
  - Linear
  - Rotary
- This lecture will focus on electric actuators



www.standoutpublishing.com/g/Actuator.html

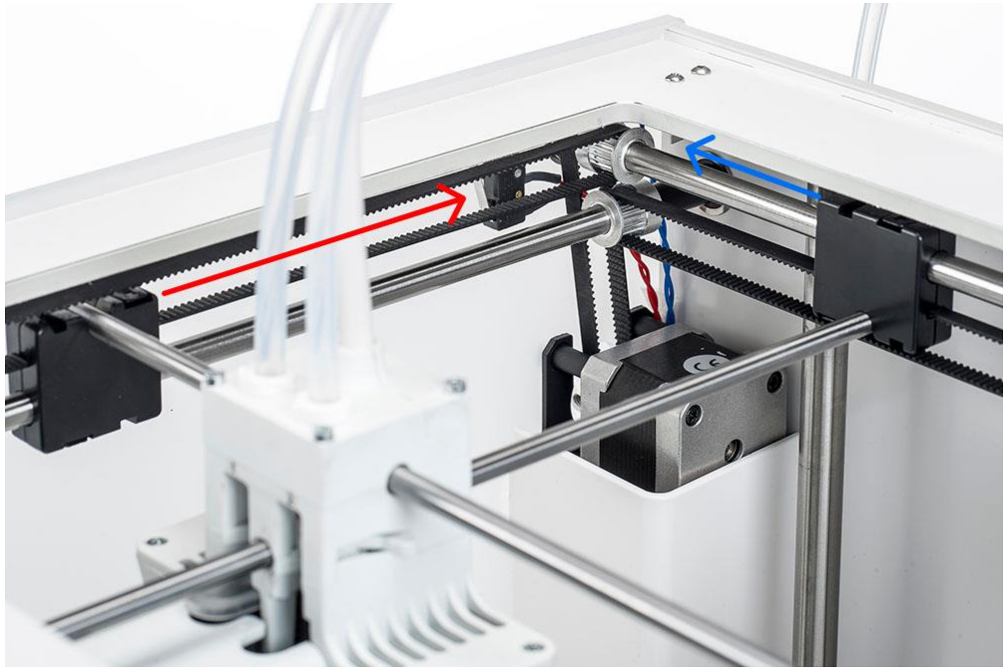
Motors

Two commonly used motors for prototyping:

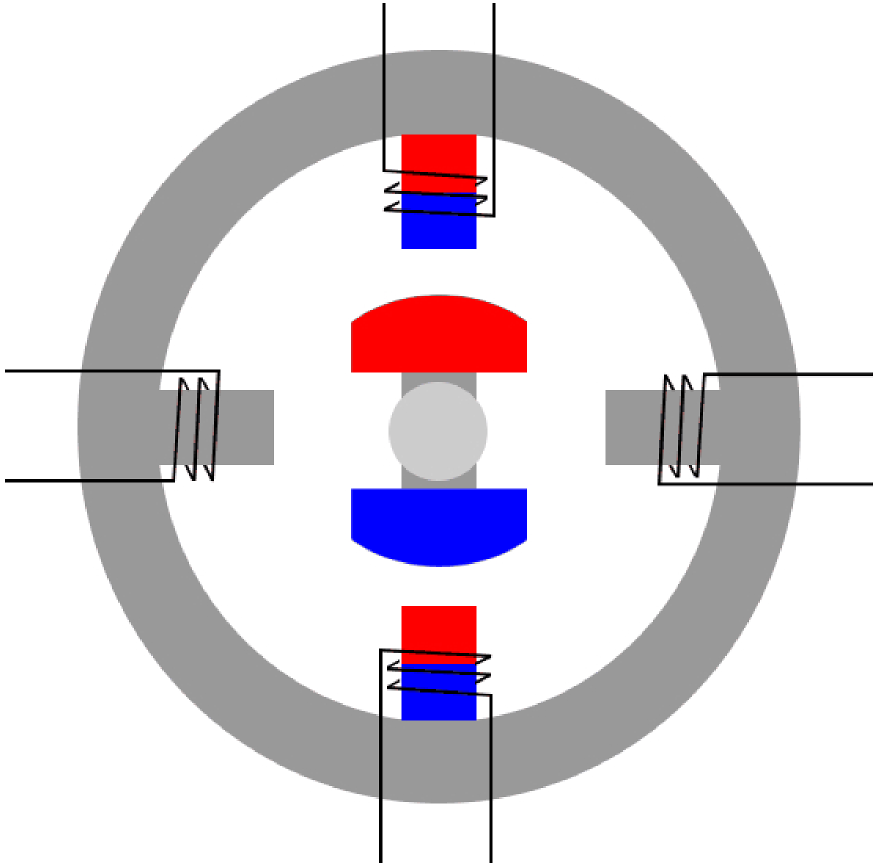
- DC motor
  - Continuous motion
- Stepper motor
  - Incremental motion

Stepper motor

- Low speed
- Precise positioning

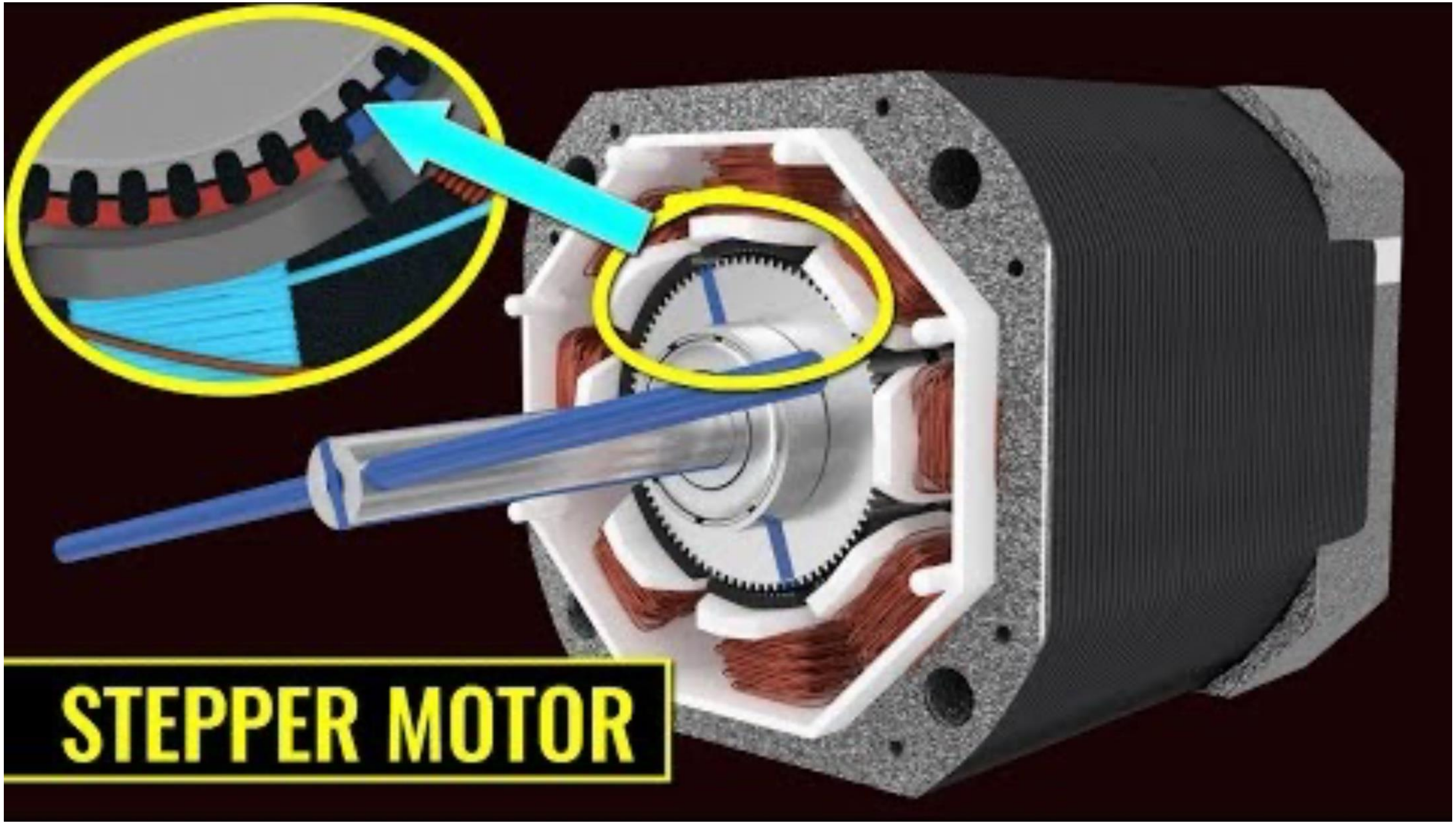


www.support.makerbot.com/s/article/1667417949865



www.drufelcnc.com/?c=blog&p=Stepper_motors

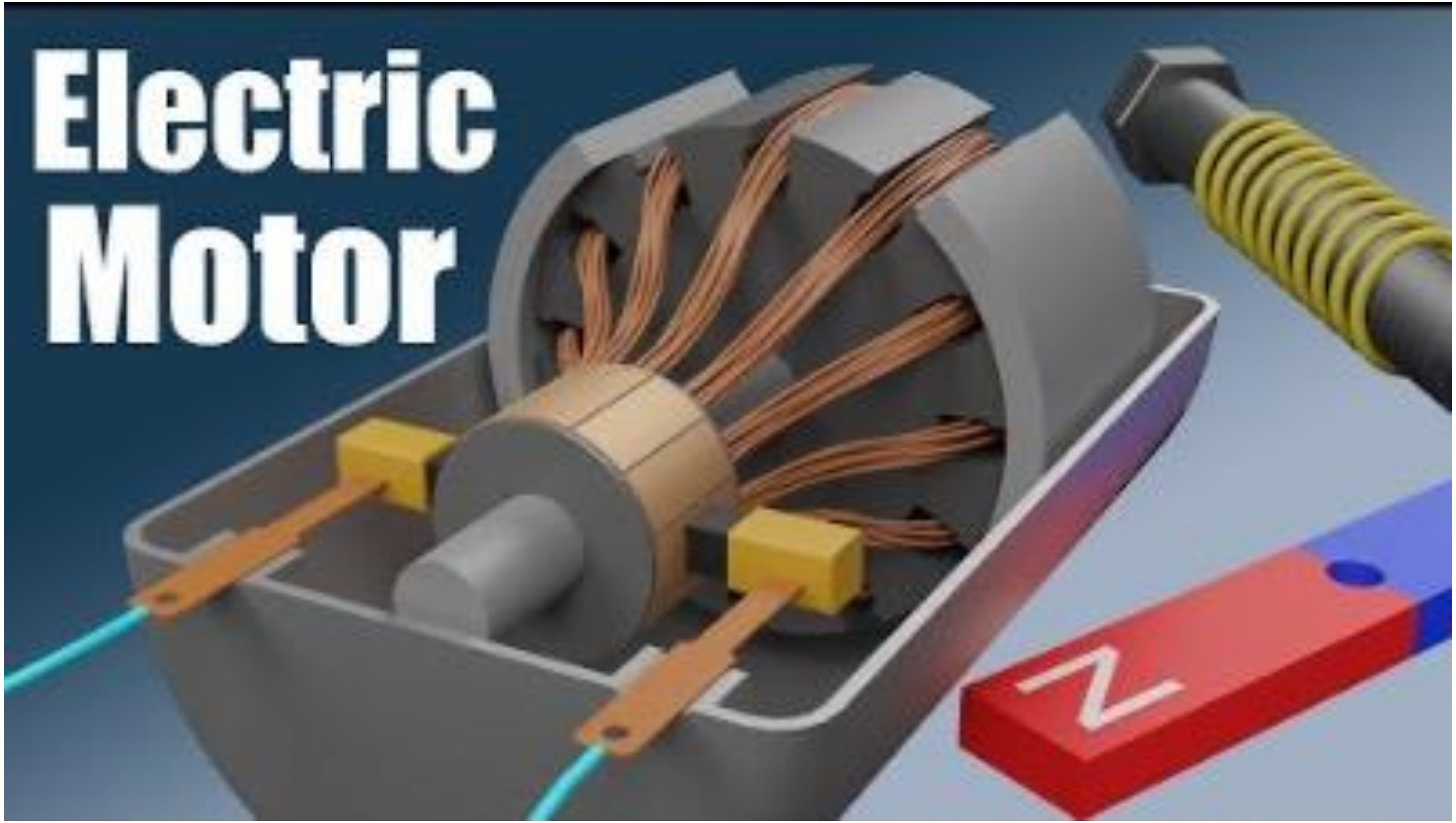
Stepper motor



DC Motor

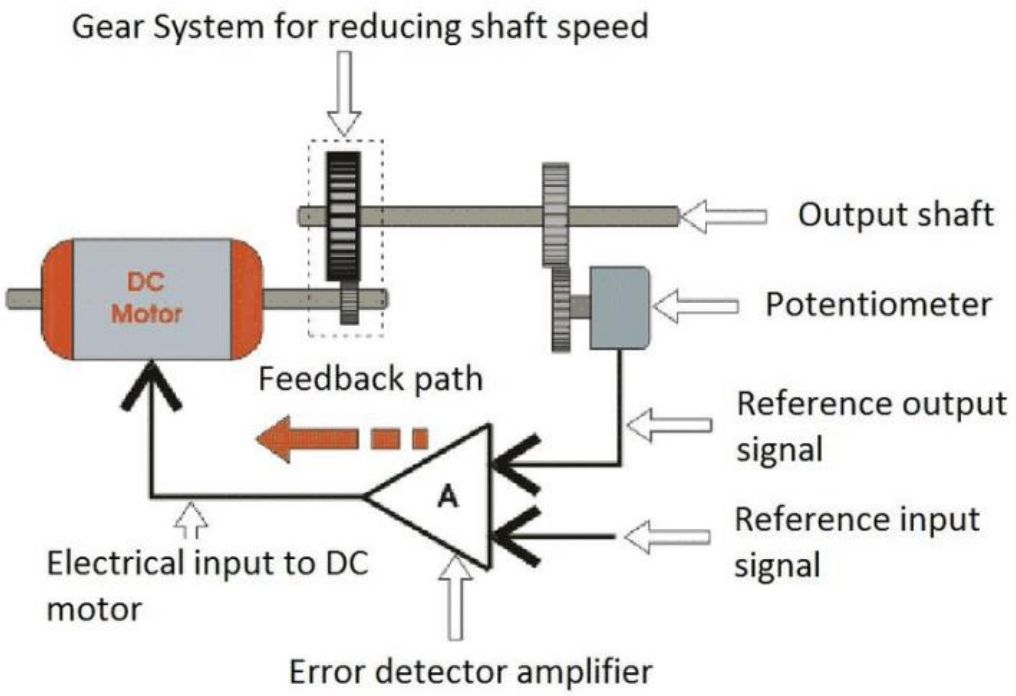
- High speed
- Higher efficiency
- No position control

DC Motor



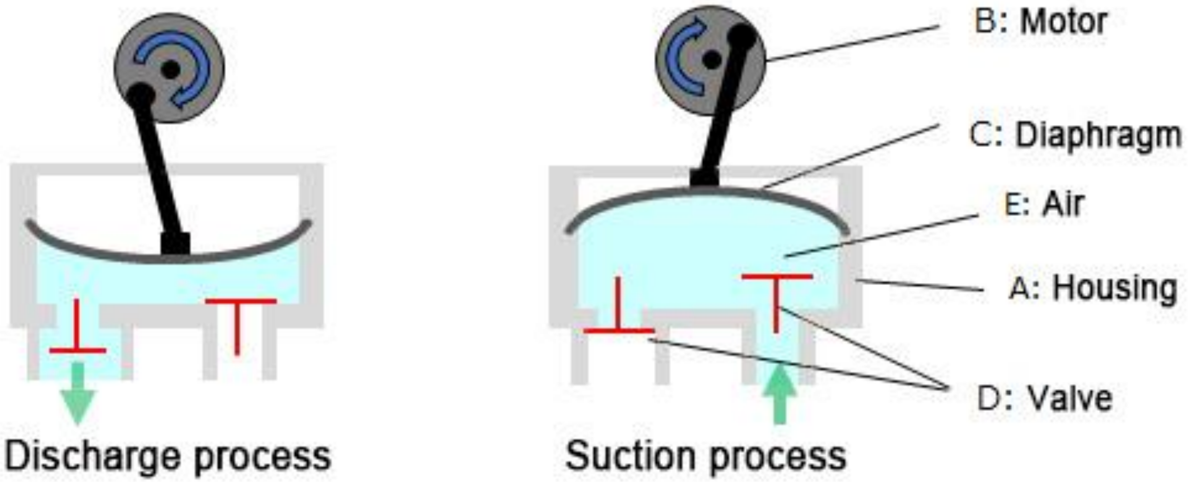
Servo motor

- DC motor in a closed-loop system
  - DC motor
  - Gearbox
  - Potentiometer
  - Error detector
- Positional servo (0-180 degrees, control position)
- Continuous servo (control speed)



www.electrialstandards.blogspot.com/2014/07/servo-motor-working-principle-servo.html

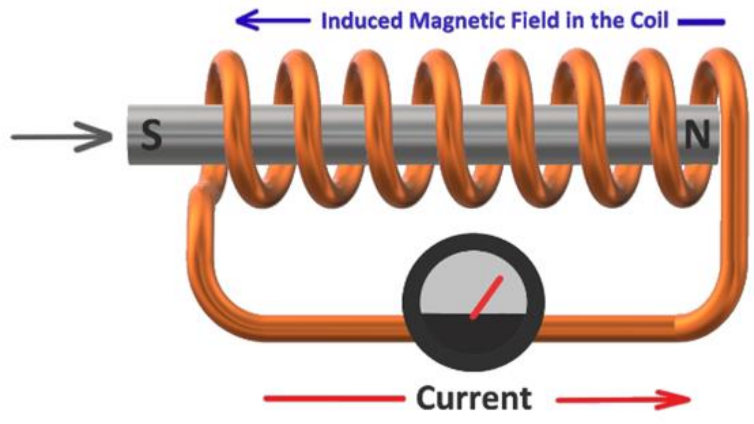
DC Motor Diaphragm Pump

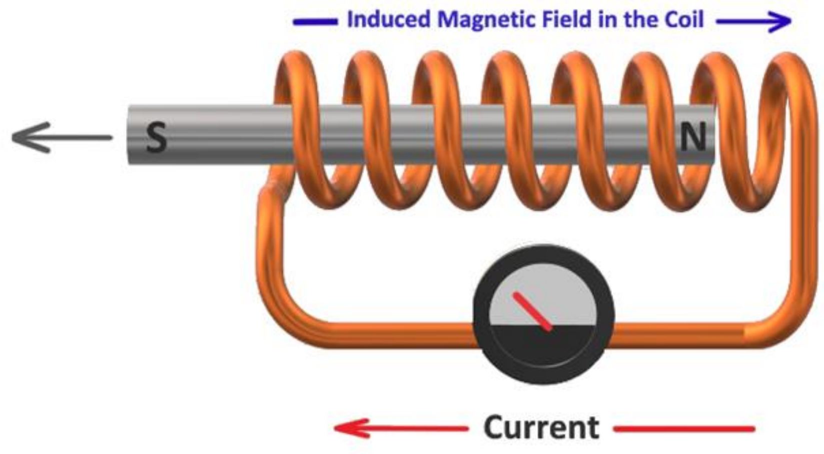


www.murata.com/en-eu/products/mechatronics/fluid/overview/basics

Solenoid

- Composed of wire coil, plunger and housing
- Magnetic field draws in the plunger





A basic, linear solenoid

Power is applied...

Computation

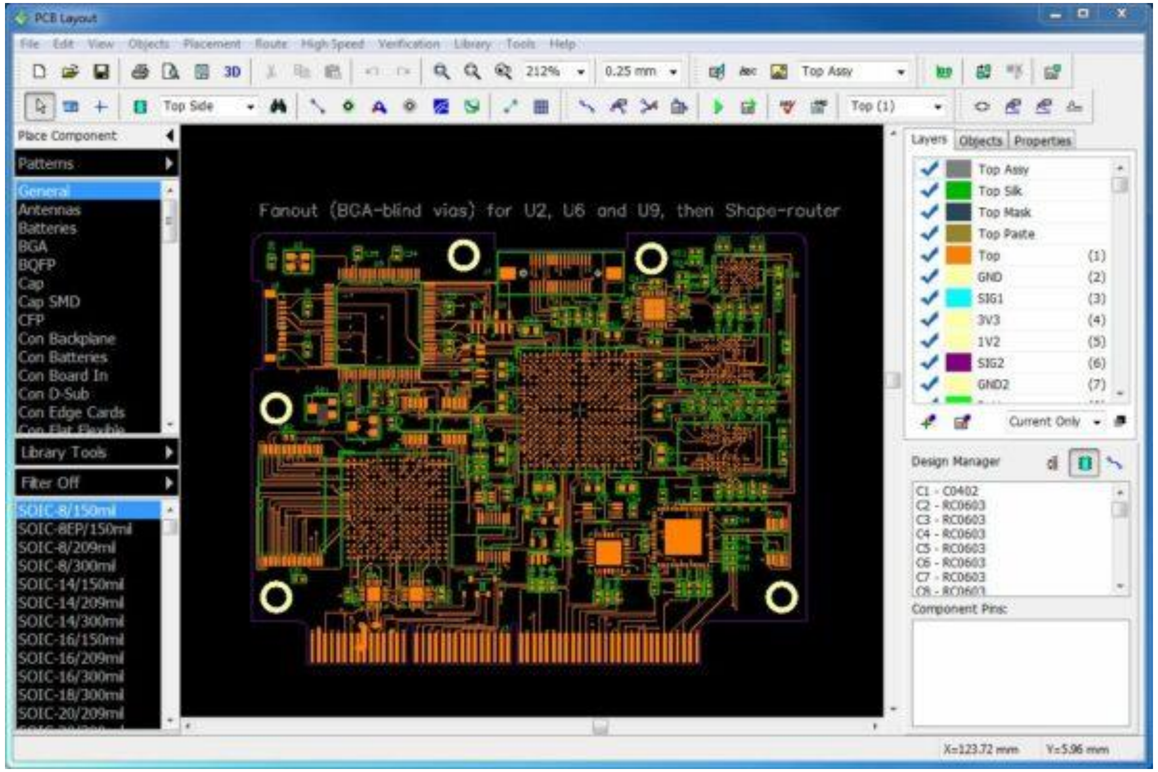
- Registering, organizing, and responding to sensory inputs
- Embedded systems: combination of computer hardware and software designed for a specific application

Embedded Systems

- Typical characteristics of embedded systems
  - Microcontroller-based
  - Application-specific/ single-purpose
  - Constraints on costs/size/energy consumption
  - Real-time response required
  - Not meant to be programmed by the end user
  - Reactive: connected to a physical environment

Prototyping Embedded Systems

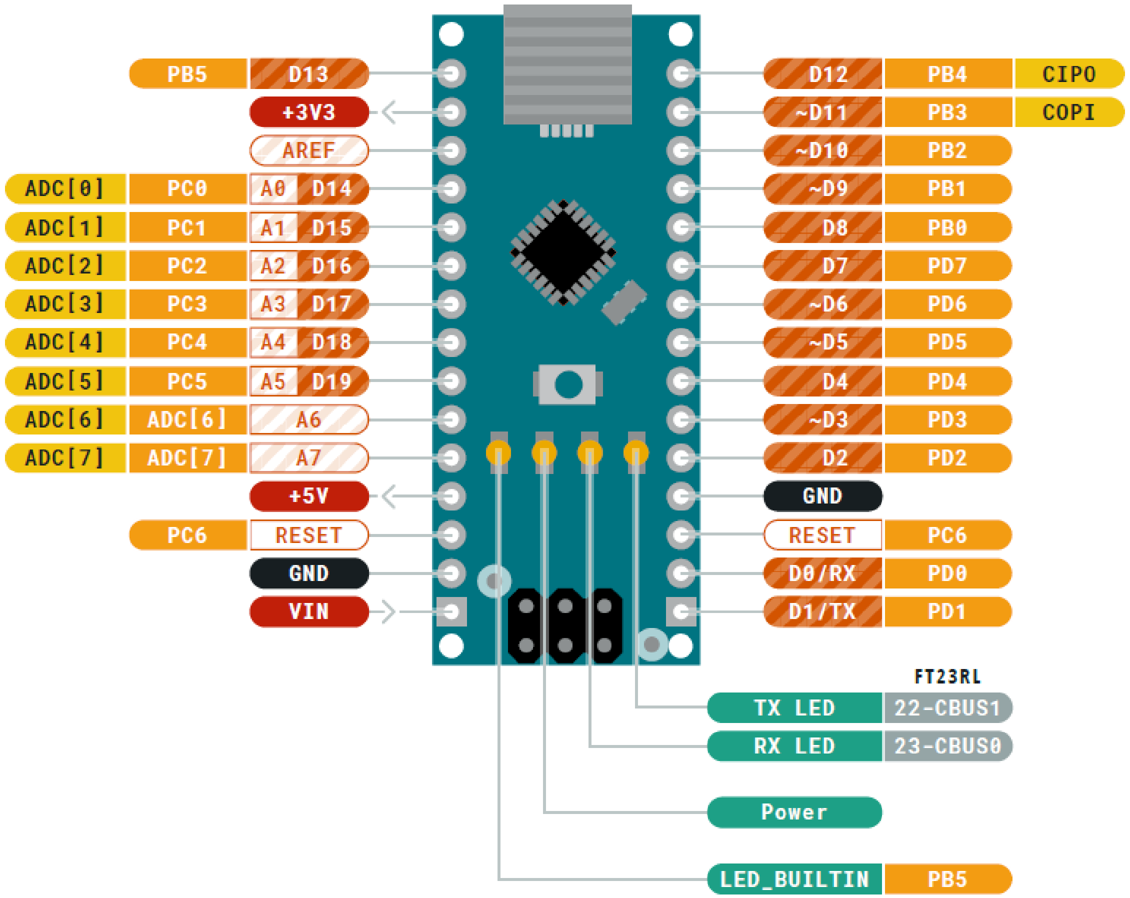
- Custom PCBs more efficient, but not suitable for prototyping
  - PCB design requires a deep understanding of electronics, programming, and PCB manufacturing
  - Large initial investment: tooling costs, design review, stencil creation: Price of 1 PCB close to that of 1000 PCBs
  - Long lead time: typically at least a month for the design and manufacturing of the PCB (depending on complexity)
  - No possibility to change or update the PCB when iterating prototypes
- Development Boards



www.bayareacircuits.com/pcb-design-layout-software-custom/

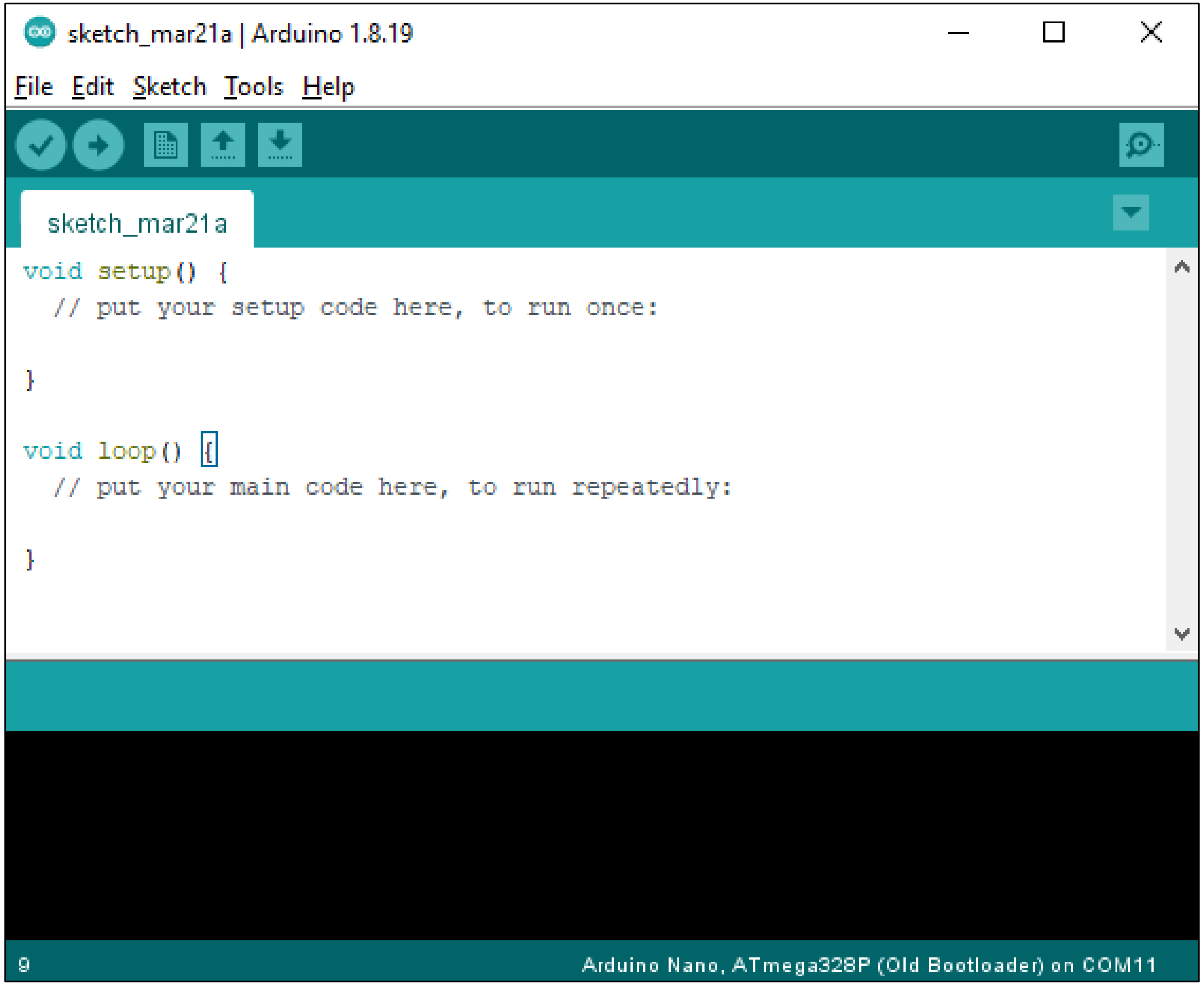
Development boards

- Development board for a microcontroller
    - Central Processing Unit (CPU)
    - Data Memory (RAM)
    - Program Memory (ROM)
    - Timers and Counters
    - Input and Output Ports (I/O)
    - Serial communication interface
    - Clock Circuit
    - Analog to Digital converter (ADC)
- Can be used for embedded applications
- Rarely all functionality is required for the same application



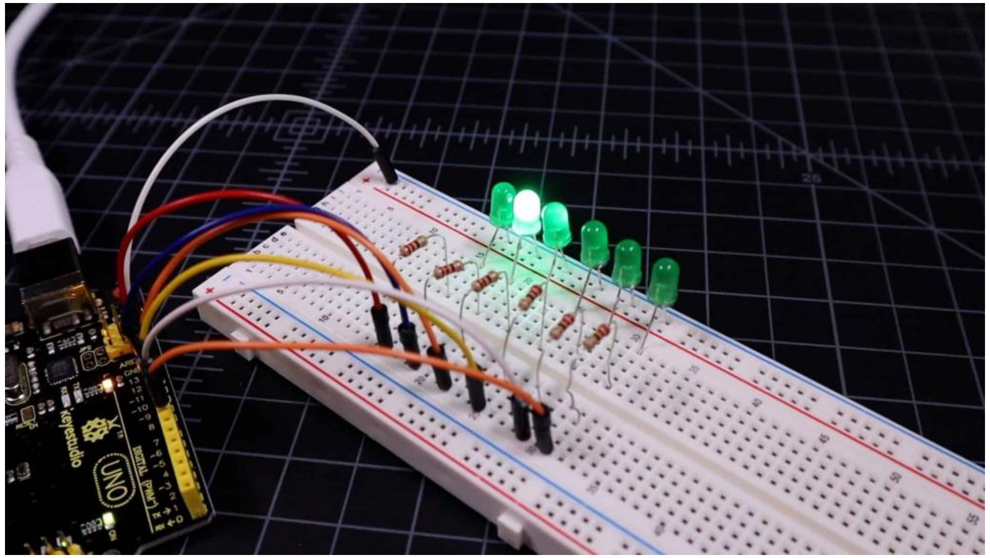
Arduino IDE

- Integrated Development Environment
- Develop, verify, compile, upload and debug
- Variant of C++ programming language
- Download for next week's lab: https://www.arduino.cc/en/software



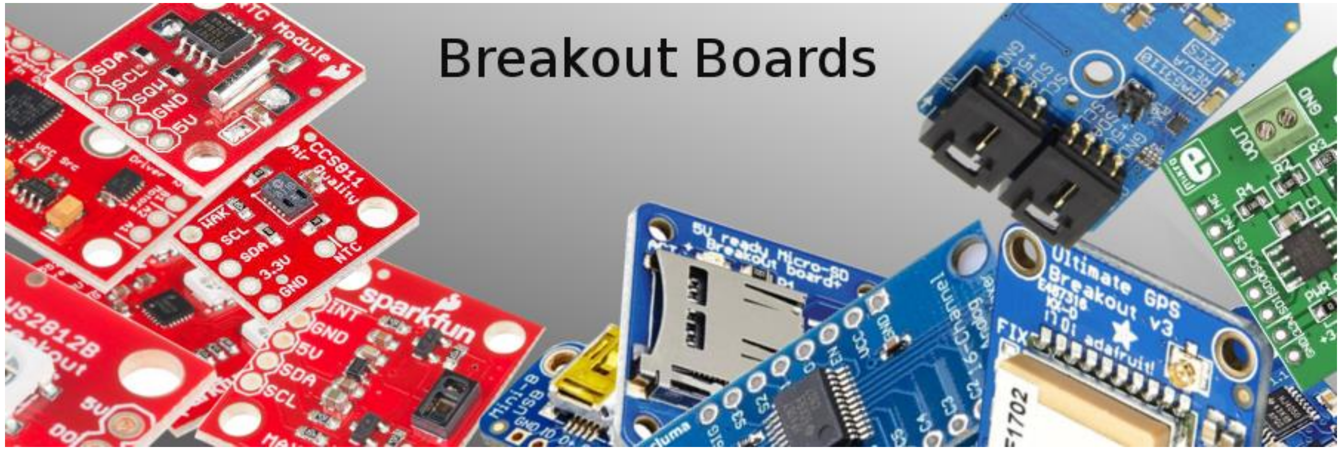
Breadboards

- A board for prototyping electronic systems

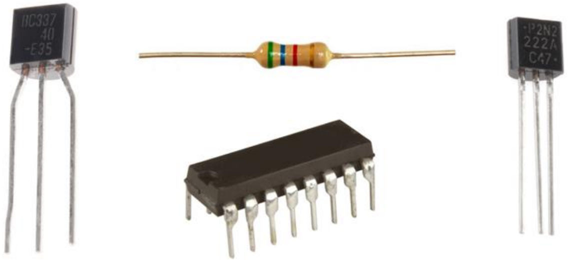


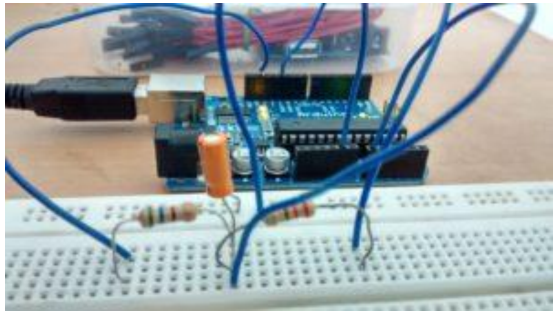
Breakout boards

- Breakout boards: Printed Circuit Boards with electronic sensors, ICs, and components with interfacing terminals
- Breakout boards with libraries for many applications
  - Temperature
  - Pressure
  - Acceleration
- Easier and more convenient way of interfacing advanced components with development boards
- More compact: surface mount device (SMD) components instead of through-hole components



www.theorycircuit.com/breakout-boards-electronics/

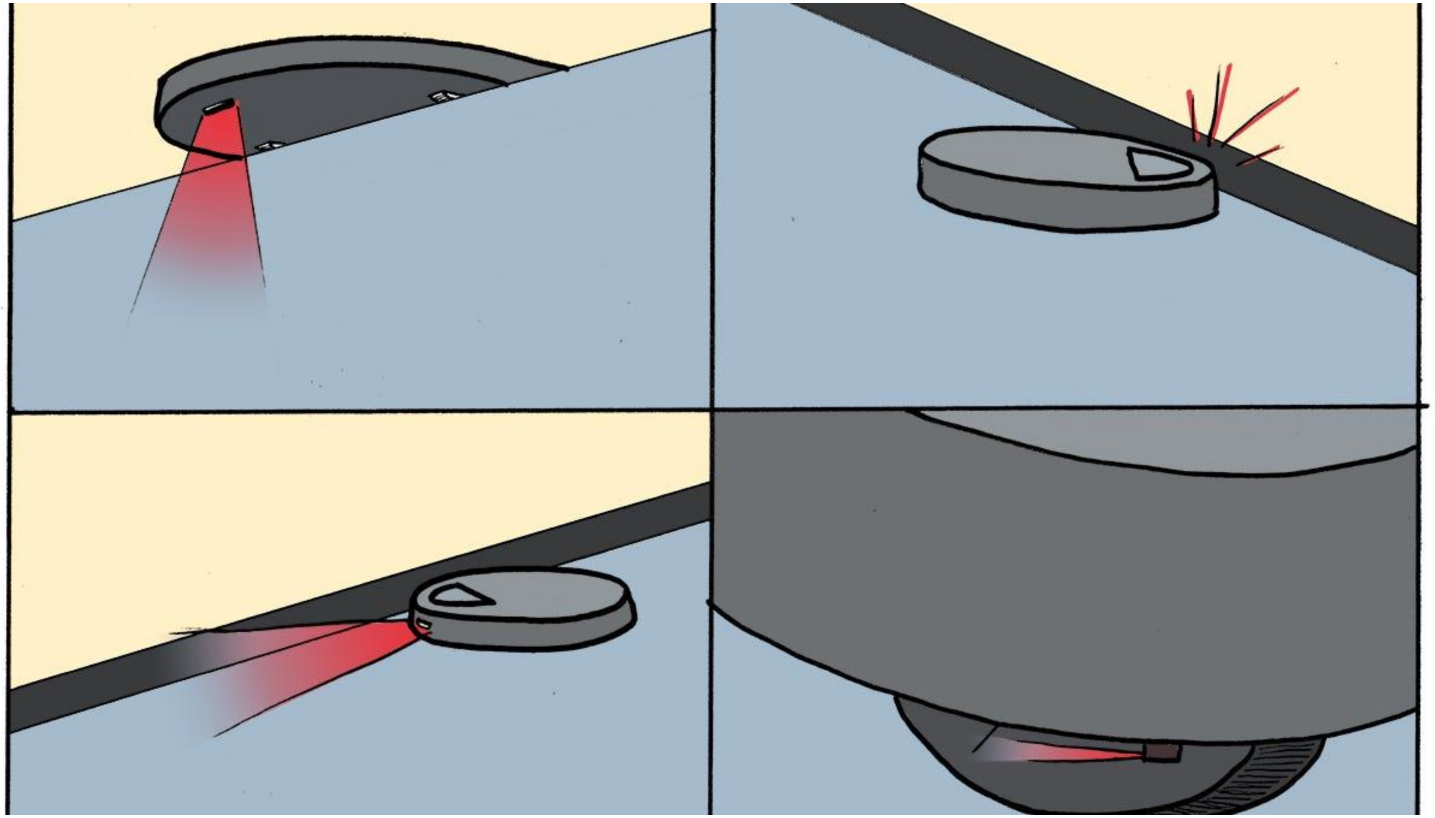




www.theorycircuit.com/breakout-boards-electronics/

Example: Robot vacuum cleaner

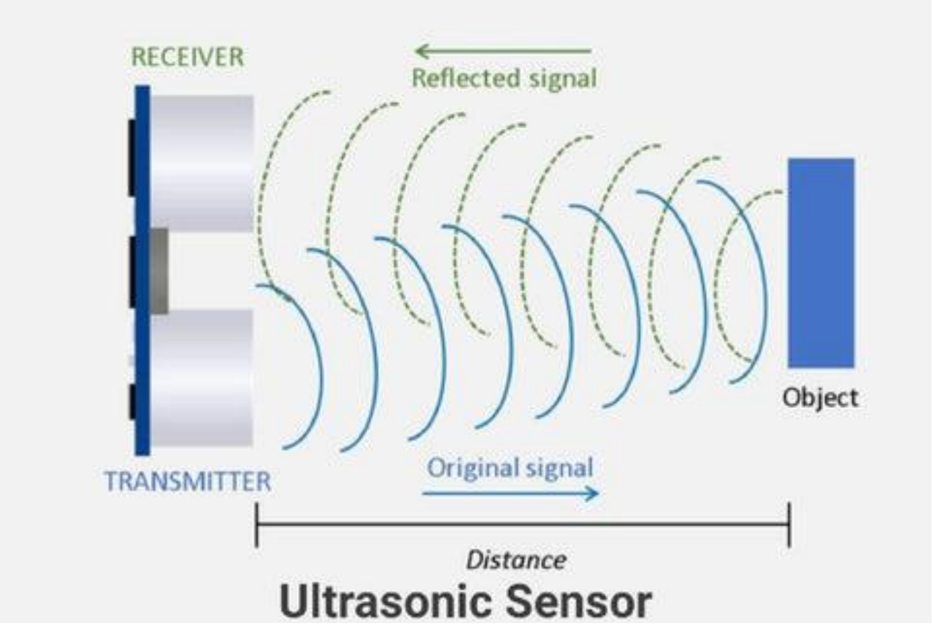
- How to detect the distance/proximity?



www.cnet.com/home/kitchen-and-household/appliance-science-how-robotic-vacuums-navigate/

Distance/proximity sensors

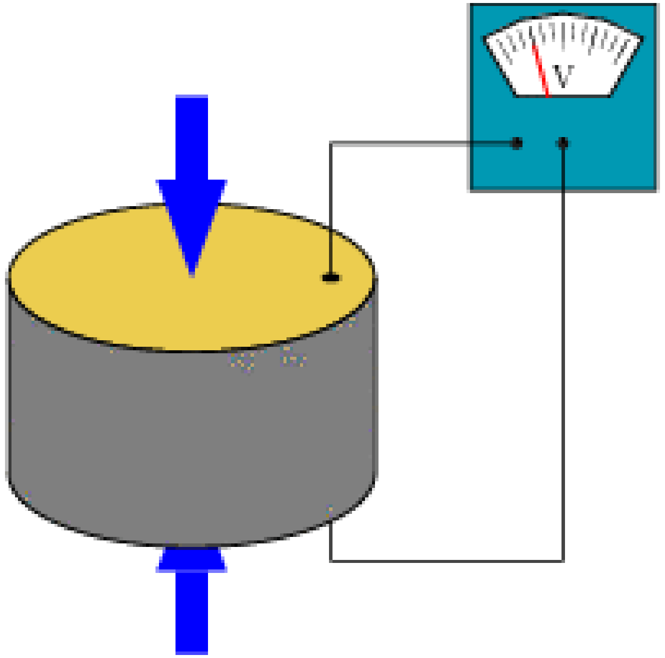
- Combination of an actuator and sensor (transmitter and receiver)
  - Infrared LED, laser, ultrasonic waves
  - Measure the intensity of the returned signal or the time it takes the signal to return
- Ultrasonic waves
  - Ultrasonic waves: sound waves with a frequency above the upper limit of human hearing
  - Also works for transparent objects
  - Distance = time x speed of sound / 2
- Reflected signal received 0.02s after sending it. What is the distance of the object?
  - $0.02s * 343ms^{-1} / 2 = 3.43m$ away



www.robocraze.com/blogs/post/what-is-ultrasonic-sensor

Distance sensor

- How to convert electrical energy to mechanical vibrations?
  - Piezoelectricity
- Piezoelectric effect: the ability of certain materials to generate an electric charge in response to applied mechanical stress
- How to convert vibrations to electrical energy?
  - Piezoelectricity



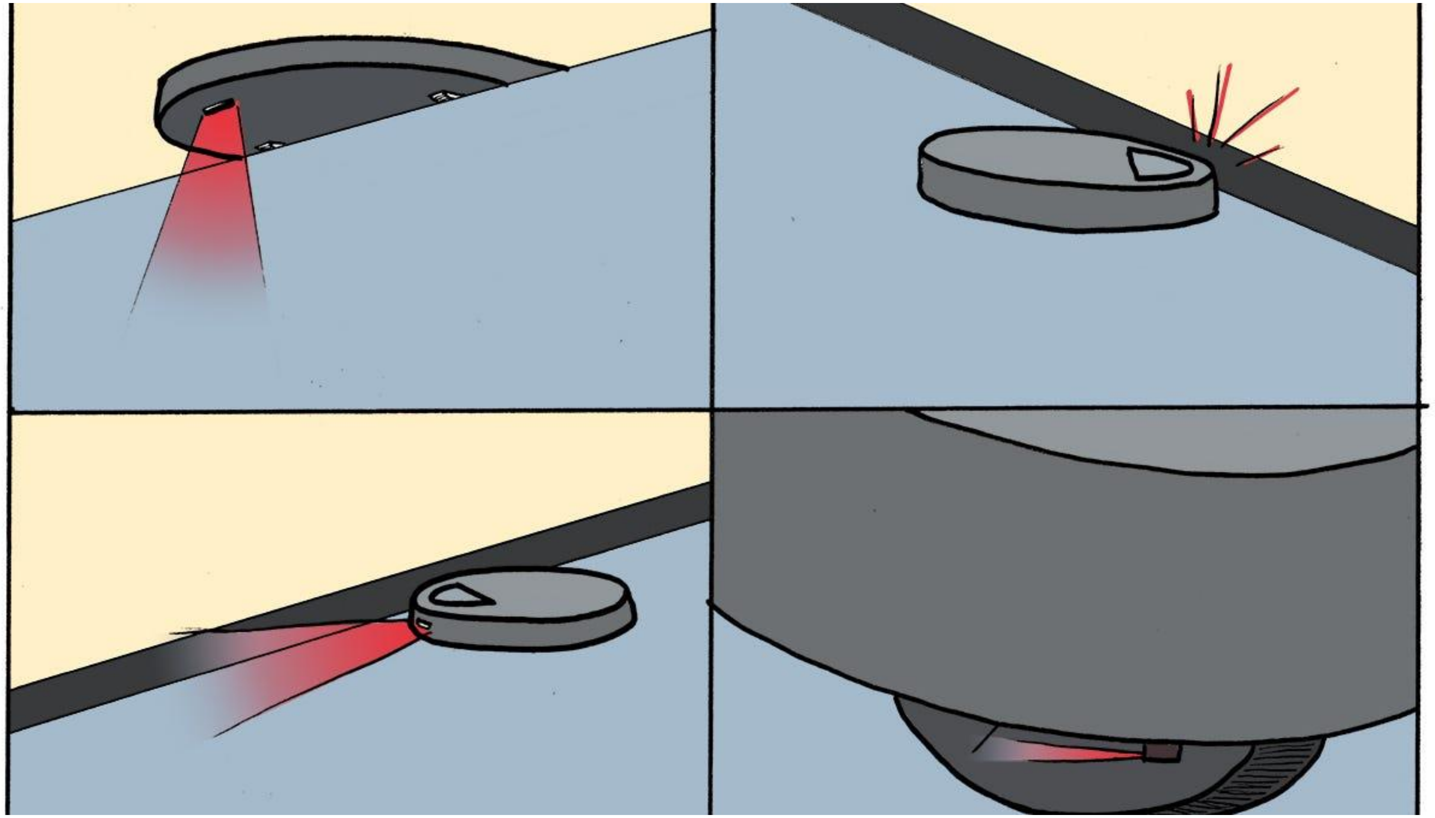
www.nl.wikipedia.org/wiki/Pi%C3%ABzo-elektrisch_effect

Distance sensor breakout board

- No need to individually control the transmitter, read out the receiver, and calculate the distance
- Transmitter and receiver integrated on a breakout board
  - No knowledge of ultrasonic piezo transducers required
- Library for high level programming
  - Reading out the measured distance does not require any knowledge regarding the working principle of the sensor

Example: Robot vacuum cleaner

- How to detect the distance/proximity?
- How to drive forward and backward?
  - DC motor



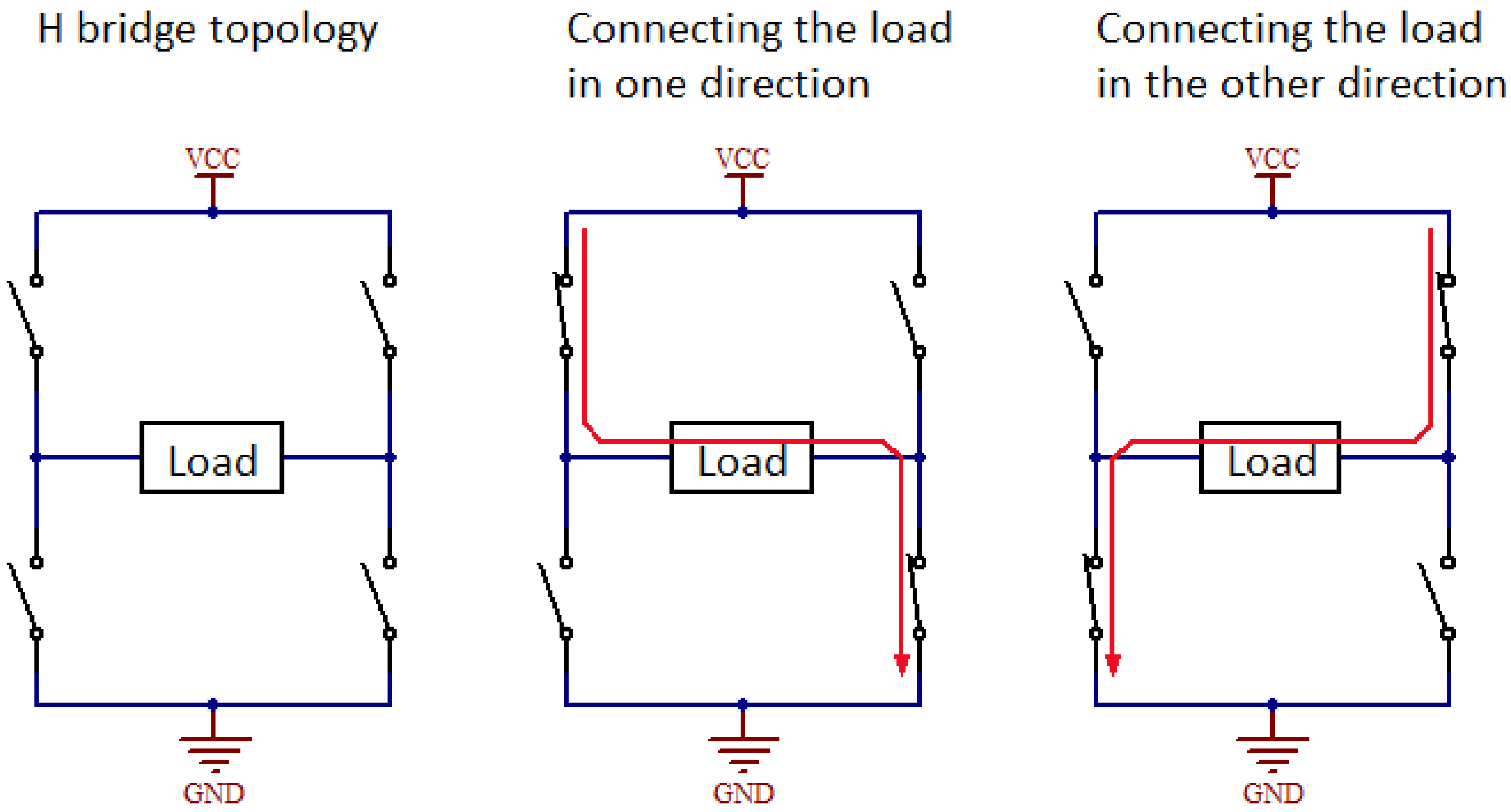
www.cnet.com/home/kitchen-and-household/appliance-science-how-robotic-vacuums-navigate/

DC Motor control

- How to control the direction of a DC motor?
- How to control the speed of a DC motor?

Controlling direction

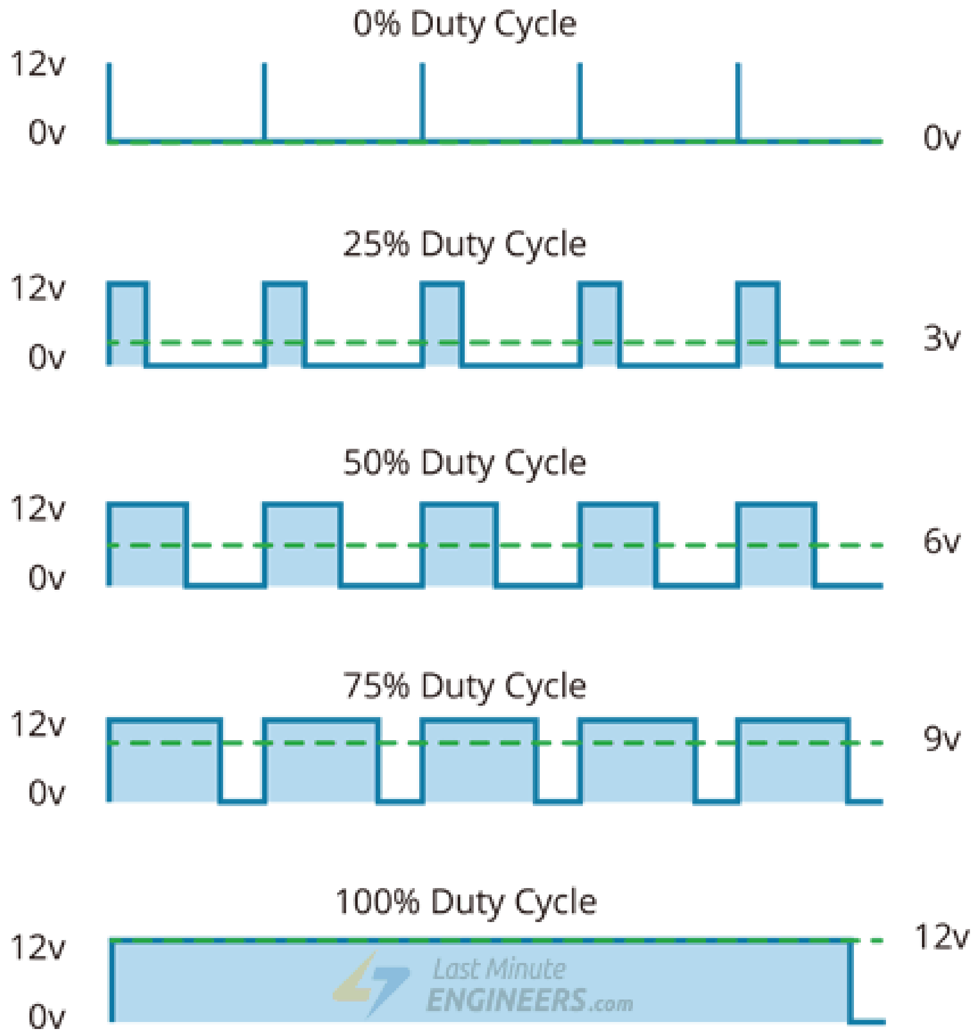
- Reverse the voltage
- H-bridge



www.axotron.se/print.php?page=34&lang=en

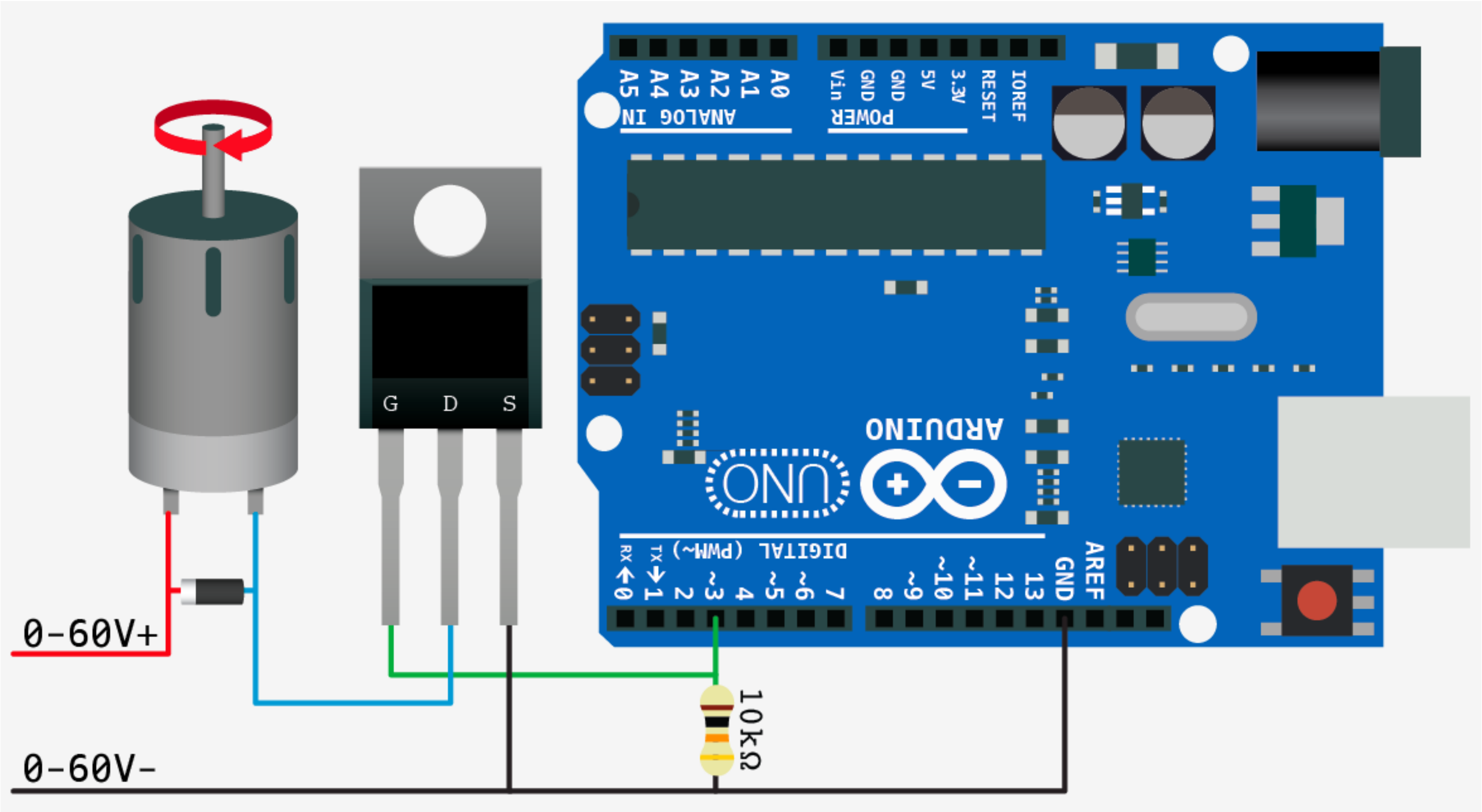
Controlling speed

- Speed of a DC motor is directly proportional to the input voltage
- Pulse-Width Modulation (PWM)
- Average voltage controlled by rapidly switching the supply between 0% and 100%
- Duty cycle: proportion of time on
- DC motor typically requires a higher voltage (e.g. 12V)
  - Arduino uses 5V logic level
- DC motor requires high power
  - Maximum output current of Arduino's digital pins is 20-40mA



Controlling speed

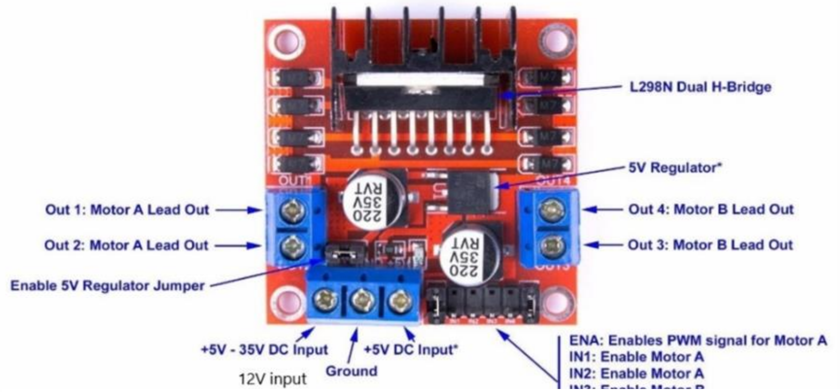
- MOSFET: control how much electricity can flow, between its source (S) and drain (D) terminals based on the amount of voltage applied to its gate terminal (G).

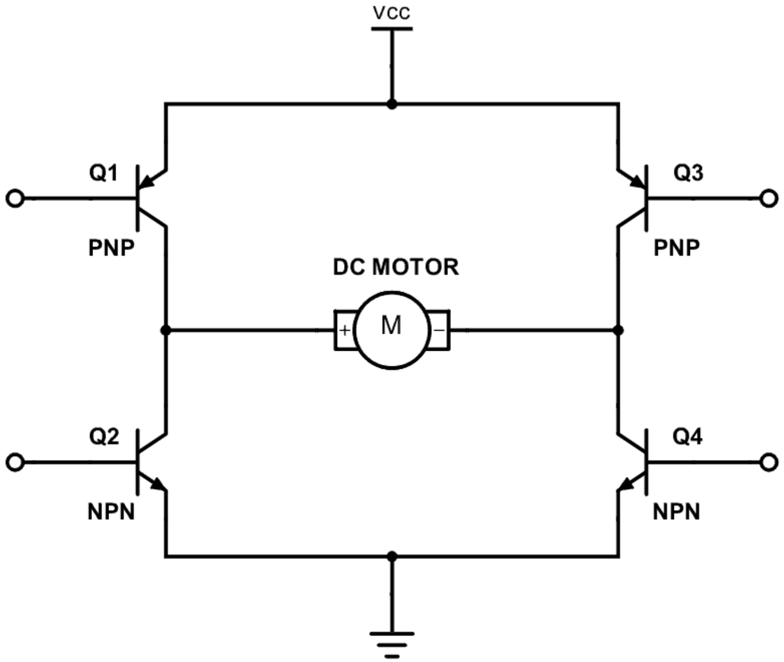


www.forum.arduino.cc/t/mosfet-for-controlling-a-dc-motor/486751

Motor driver breakout board

- L298 Motor driver board
  - H-bridge
  - MOSFETs
- Library for high level programming
  - Changing direction or speed of the motor does not require any knowledge about an H-bridge or PWM

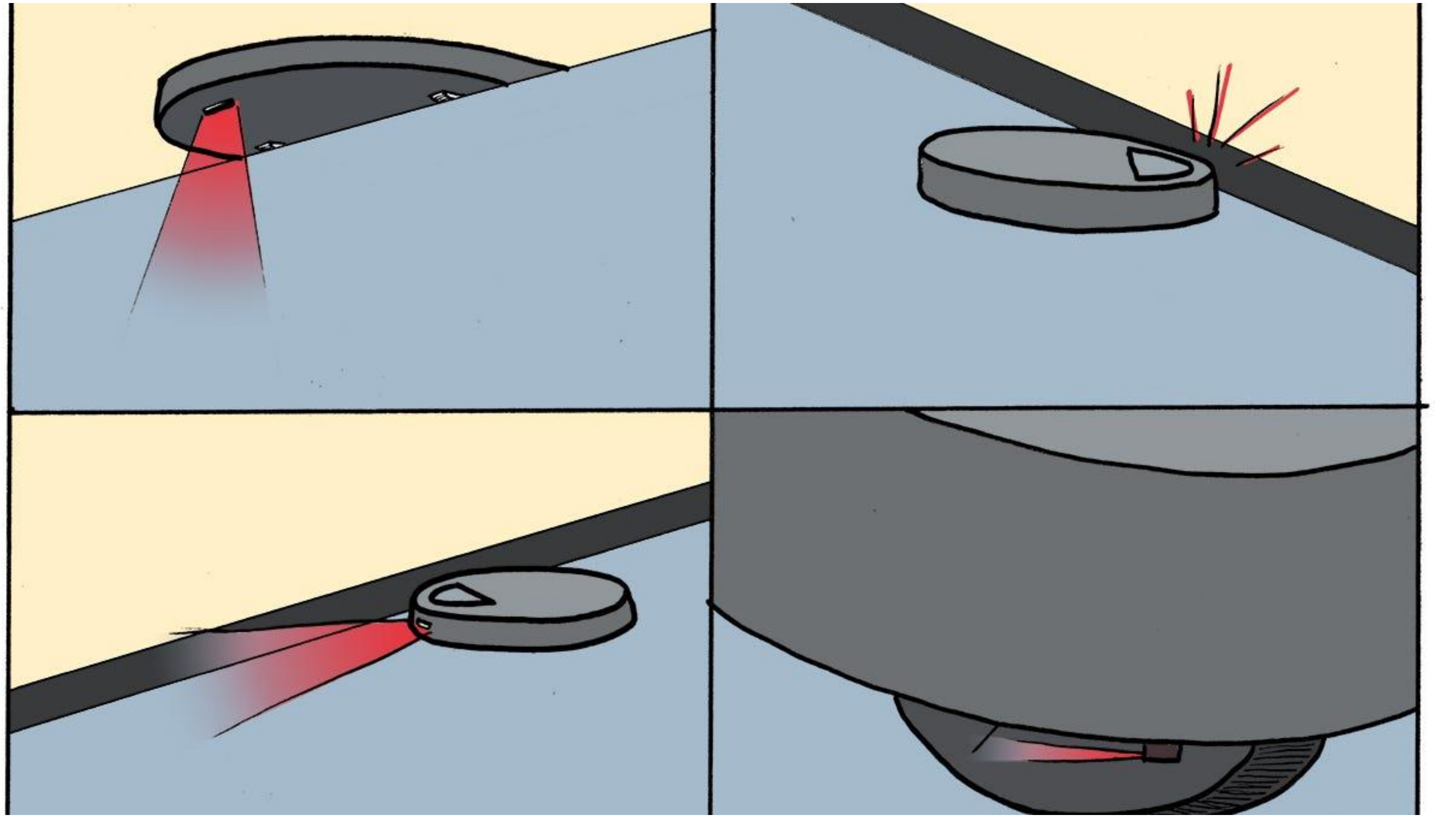




www.build-electronic-circuits.com/h-bridge/

Example: Robot vacuum cleaner

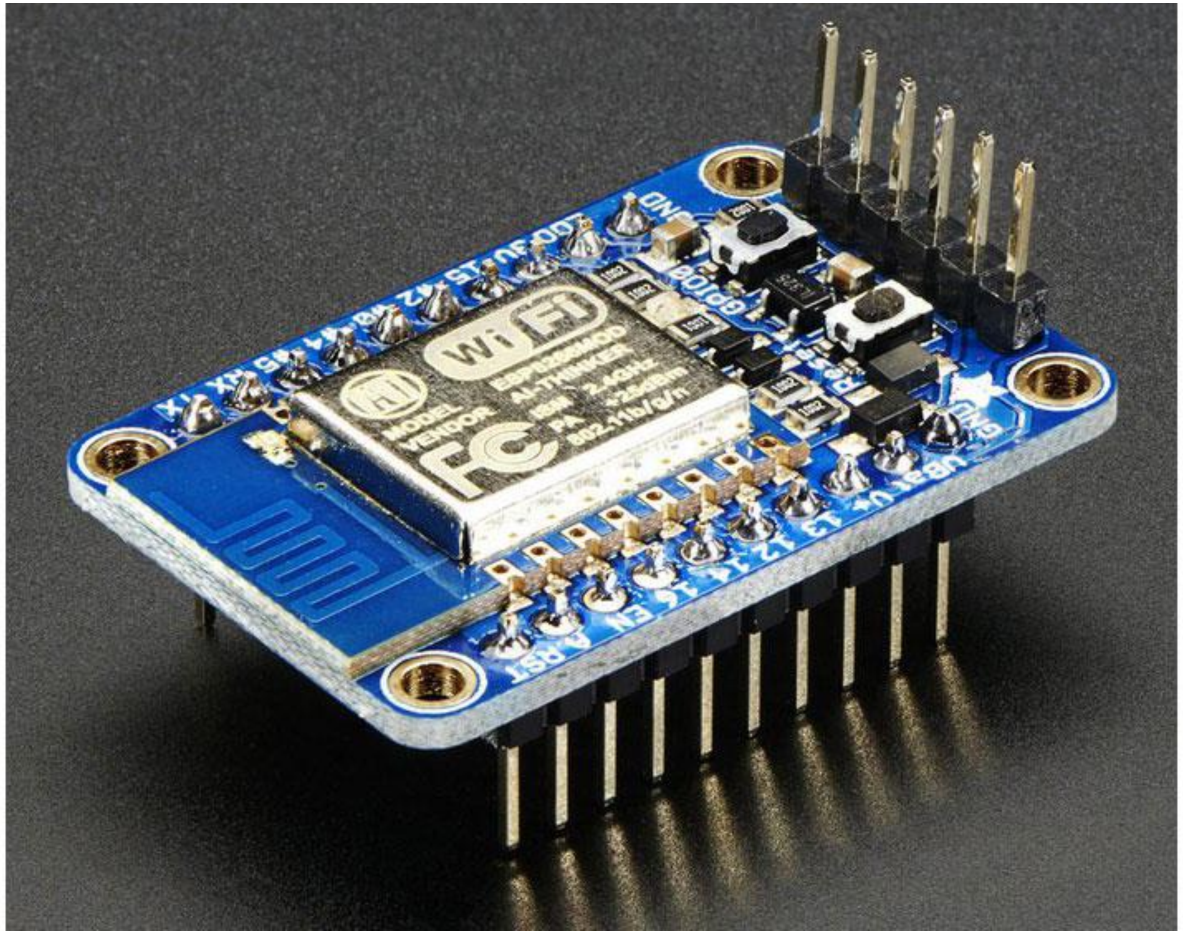
- How to detect the distance/proximity?
- How to drive forward and backward?
- How to send an app notification when the vacuum cleaner gets stuck?



www.cnet.com/home/kitchen-and-household/appliance-science-how-robotic-vacuums-navigate/

WiFi breakout board

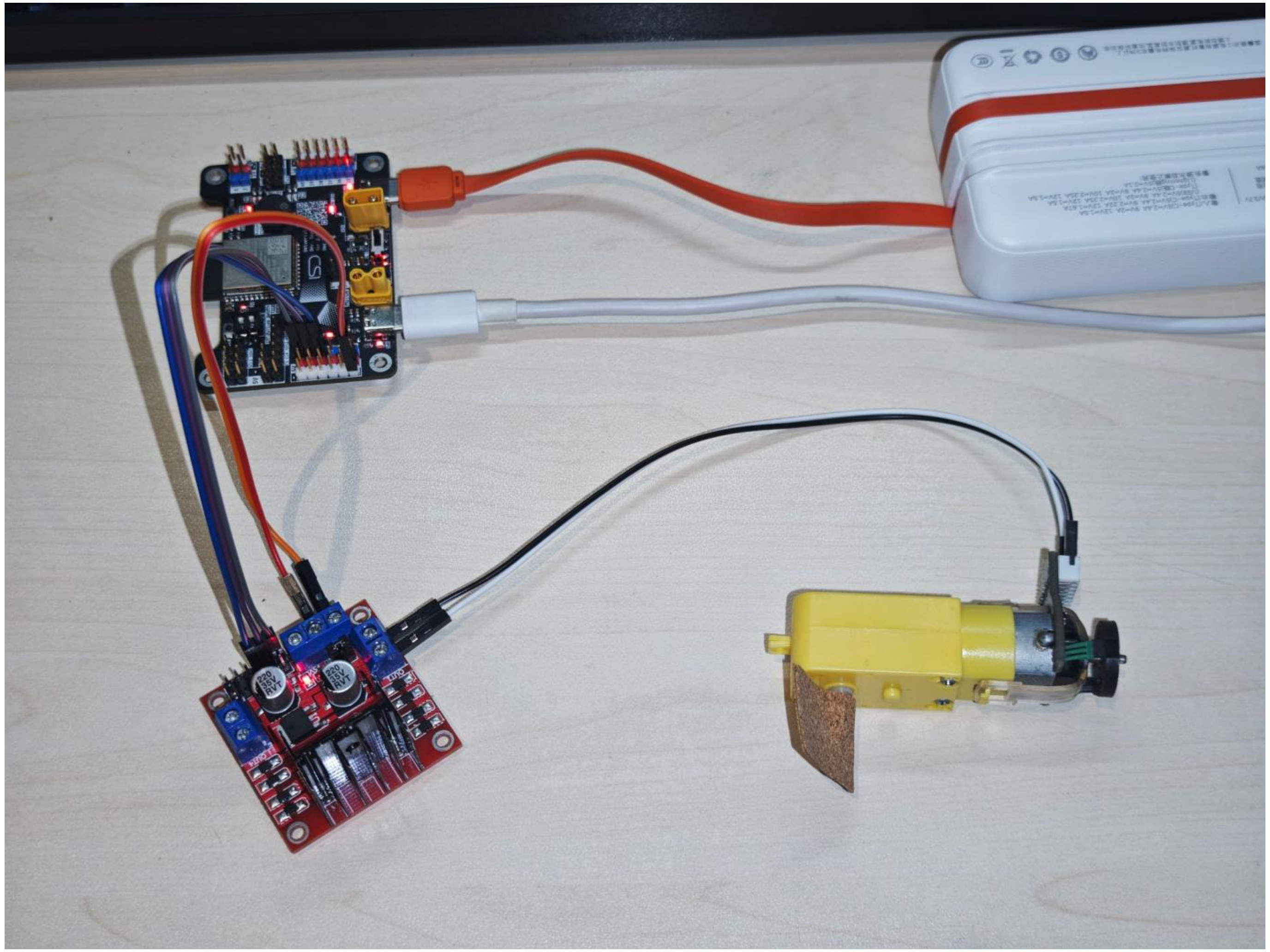
- Transmitter, receiver and library allowing for high-level programming
- Breakout boards for BlueTooth, NFC, 3G, GPS



www.digikey.com/en/maker/blogs/esp8266-breakout-boards

Next week's lab

- Use your phone to control a DC motor through WiFi
    - Turn motor on/off
    - Change the speed
    - Change the direction



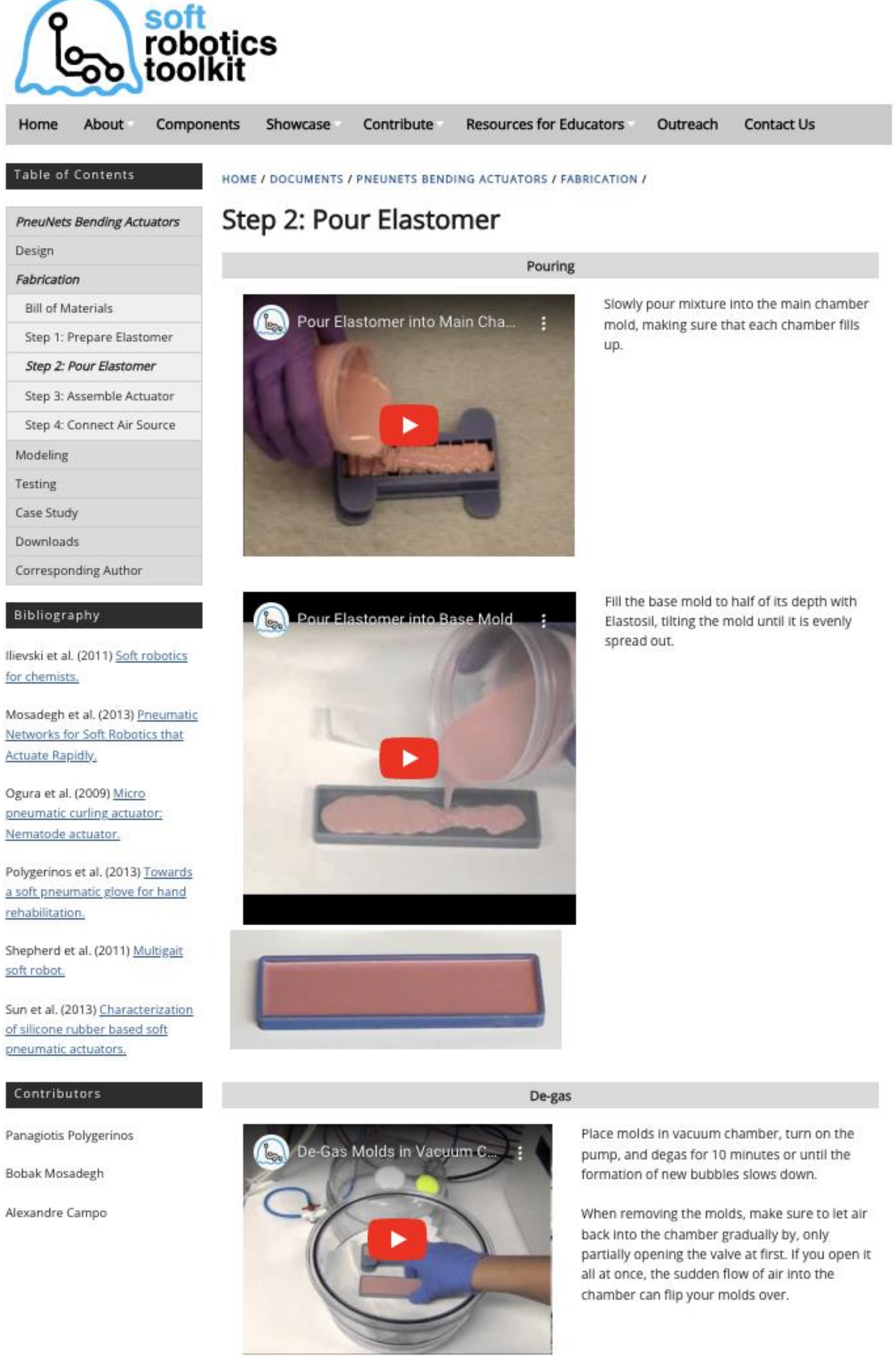
Stay on schedule for the assembly lab!

- Print the main body of the fish (**Part #1** and **part #2**, plan to use battery and *remote control? Make sure to close the opening for the cablein the CAD-file before printing!)*
- Print the caudal fin of the fish (**Part #3**)
- Print the pectoral fin (**Part #4**, *x*2)
- Print the anal and dorsal fin (**Part #5**, *x*2)
- Print the tail segments of the fish (**Part #6**, **part #7**, **part #8**, and **part #9**)

Questions?

Final report

- Detailed build instructions for your robotic fish
  - Step-by-step fabrication and assembly images, videos, illustrations
  - List of tools and materials needed, links to CAD/fabrication files
  - Evaluation: can a layman replicate your design based on the report
  - 20p limit (mostly images!)



www.softroboticstoolkit.com/book/pneunets-step-2