Sensors, Actuators and Controllers

Sensors

- Sensors detect aspects of an environment

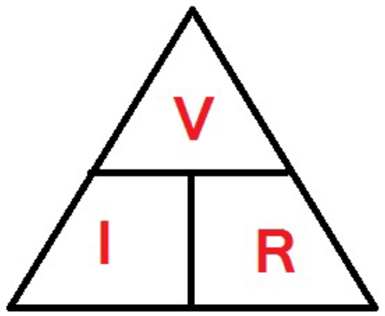
- **Input:** Sensors can measure parameters such as temperature, pressure, humidity, motion, light, sound, chemical composition, or even biological properties.

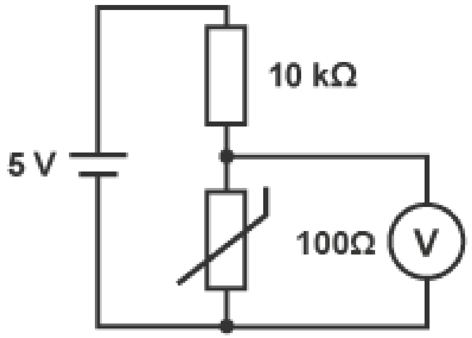
- **Output**: The output of a sensor is usually an electrical signal that corresponds to the measured property. This signal is often processed and used by other systems or devices.

Voltage divider circuit

- To measure sensors which are resistance based a potential divider is often used

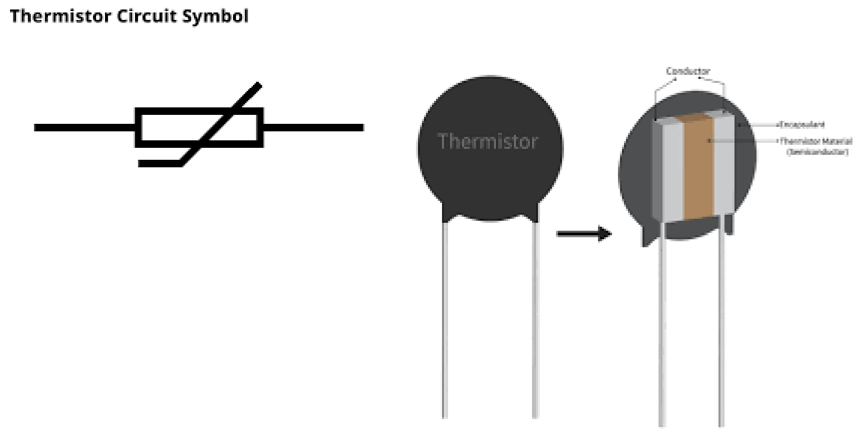
- A potential divider converts resistance change into a measurable voltage change, which is easier for most microcontrollers or measuring devices to process.



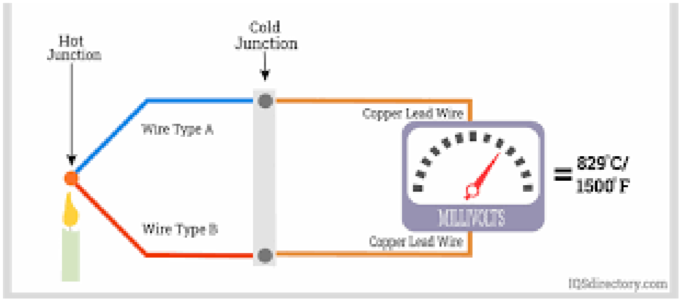


Temperature Sensors

- **Purpose:** Measure the temperature of the environment, equipment, or processes.
- **How they work:** Convert changes in heat into electrical signals that can be read by control systems.
- **Common Types:**
  - Thermocouples – robust, wide temperature range, often used in industry.
  - Thermistors – very sensitive to small changes, used in devices like digital thermometers. Two types: Negative temp coefficient (NTC) and positive temp coefficient (PTC)

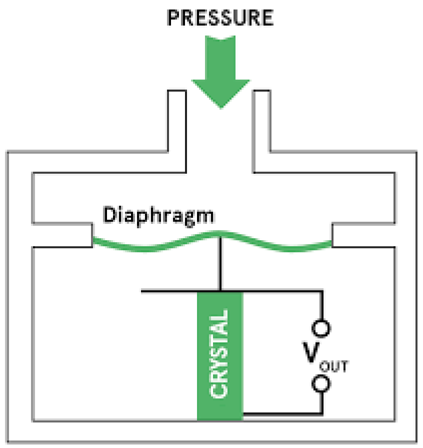


Thermistor – outputs resistance



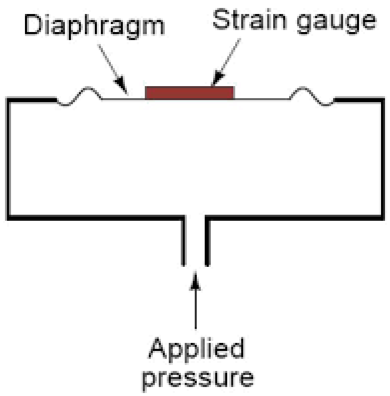
Thermocouple – output voltage

Pressure Sensors



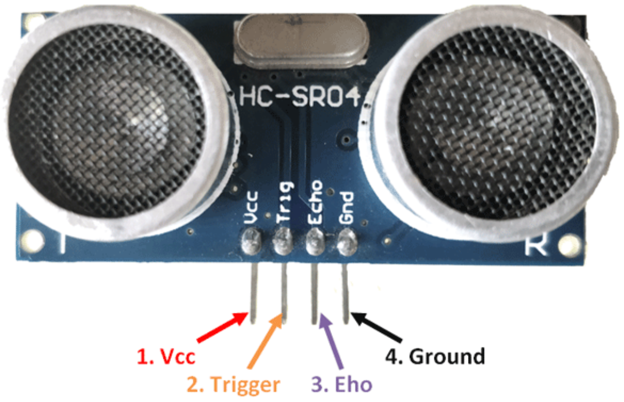
Piezoelectric pressure sensor – output voltage

- **Purpose:** Measure the pressure of gases and liquids.
- **How they work:** Convert force from the fluid (gas or liquid) pressing on a surface into an electrical signal.
- **Common Types:**
  - Strain Gauge – pressure causes a thin diaphragm to bend; this stretches the strain gauge, changing its resistance.
  - Piezoelectric – pressure produces a tiny voltage in certain crystals when they are squeezed.
- **What happens when pressure increases:**
  - In a strain gauge, resistance increases or decreases depending on how it is stretched.
  - In a piezoelectric sensor, a larger voltage is generated as pressure rises.



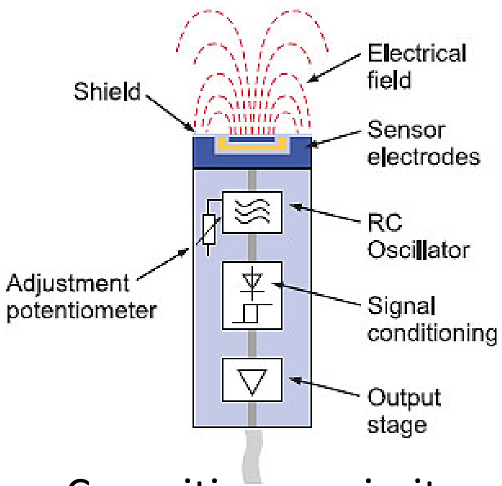
Strain Gauge – output voltage

Ultrasonic sensor with pinouts – output voltage



Proximity Sensors

- **Purpose:** Measure how far away an object is, or detect its presence, without physical contact.
- **How they work:** Send out a signal (sound wave, electromagnetic field, or light) and detect changes when something comes close.
- **Common Types:**
  - Ultrasonic – send out high-frequency sound waves; the sensor measures the time taken for the echo to return to calculate distance.
  - Capacitive Proximity Sensor – detects changes in capacitance when an object (often something conductive or with water content) comes near.
- **What happens when an object gets closer:**
  - Ultrasonic: shorter echo time → smaller calculated distance.
  - Capacitive: capacitance increases, so the sensor outputs a signal.



Capacitive proximity sensor – output voltage

Light Sensors

- **Purpose:** Measure the intensity (brightness) of light in the environment.
- **How they work:** Convert light energy into a change in resistance or an electrical signal.
- **Common Types:**
  - LDR (Light Dependent Resistor) – resistance decreases as light intensity increases, allowing more current to flow.
  - Photodiode – produces a small current when exposed to light; brighter light creates a larger current.
- **What happens when light increases:**
  - LDR: resistance goes down → current rises.
  - Photodiode: current output rises with more light.

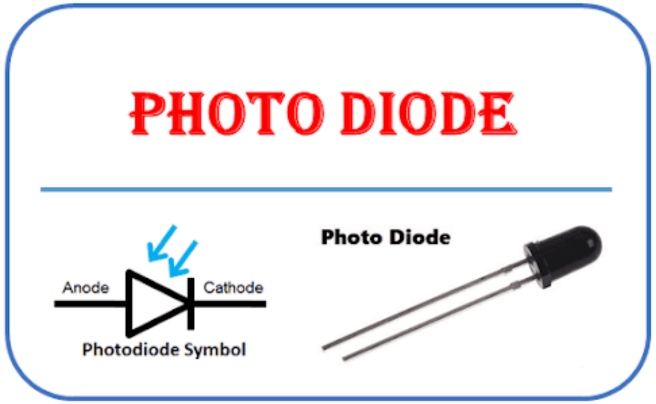
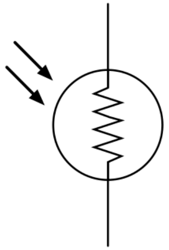
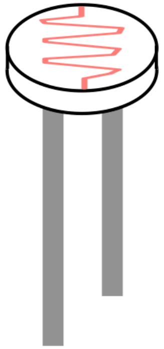


Photo Diode – Output voltage

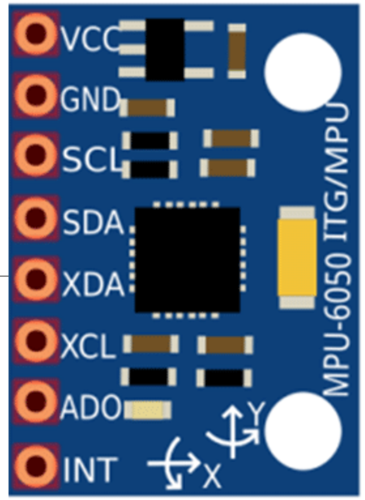


LDR circuit symbol

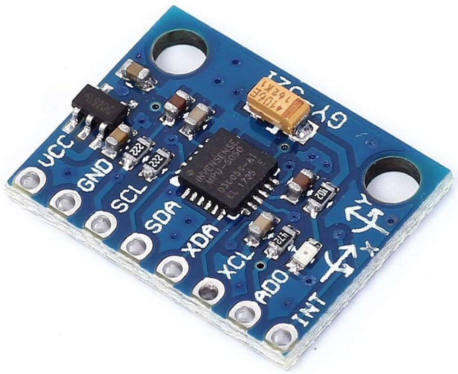


LDR – Output resistance

Motion Sensors



- **Purpose:** Detect movement, tilt, rotation, or vibration.
- **How they work:** Use tiny mechanical structures on a chip that shift or vibrate when the device moves, converting this into an electrical signal.
- **Common Types (often combined in one chip):**
  - Accelerometers – measure acceleration and tilt (e.g., how quickly something speeds up or the angle it is tilted).
  - Gyroscopes – measure rotation or angular velocity (how fast something spins).
- **Example Device:**
  - MPU6050 – a popular motion sensor module that combines a 3-axis accelerometer and a 3-axis gyroscope in one chip.



An accelerometer – Output is either voltage for analogue or a signal for digital

Switches & Buttons

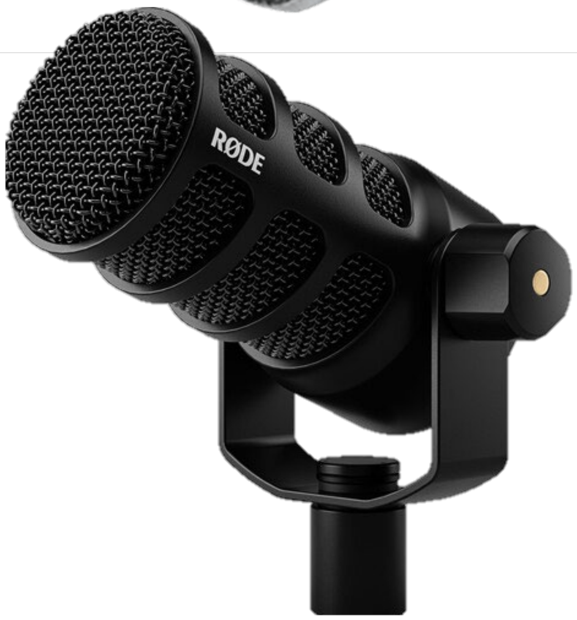
- **Purpose:** Used as simple sensors to detect user input or the position of a machine part.
- **How they work:** Open or close an electrical circuit when pressed, flipped, or triggered. This change in circuit state acts as a digital signal (“on/off”).
- **Common Types:**
  - Push Button – pressed by the user to send a short signal (e.g., start/stop, reset).
  - Toggle Switch – stays in position until flipped (on/off control).
  - Micro/Limit Switch – activated by machine parts reaching a certain position.
- **What happens when pressed or switched:**
  - Circuit changes from open → closed (ON) or closed → open (OFF).
  - Provides a clear digital signal for controllers to act on.

Cameras

- **Purpose:** Capture images or video to sense the environment in detail.
- **How they work:** Light passes through a lens onto a sensor (CCD or CMOS), which converts the light into electrical signals to form a digital image.
- **What happens when light changes:**
  - Brighter light produces stronger signals (clearer image).
  - Low light produces weaker signals (darker/noisier image).

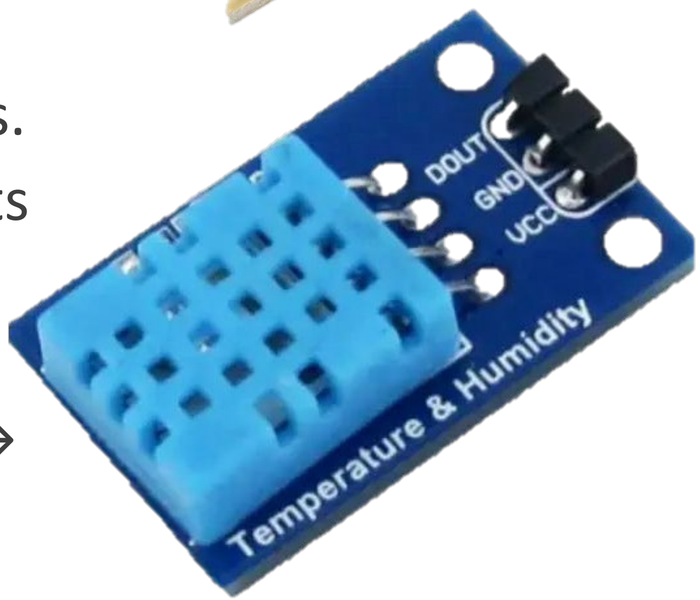
Sound Sensors (Microphones)

- **Purpose:** Detect sound waves or vibrations in the air and convert them into electrical signals.
- **How they work:** A diaphragm inside the sensor vibrates when hit by sound waves. These vibrations are turned into changes in voltage or current.
- **Common Types:**
  - Condenser Microphone – very sensitive, used in audio equipment.
  - Electret Microphone – small, low-cost, often used in phones and sensors.
- **What happens when sound increases:**
  - Louder sound → diaphragm vibrates more → bigger electrical signal.



Moisture / Humidity Sensors

- **Purpose:** Measure the amount of water present in air (humidity) or in materials like soil.
- **How they work:**
  - Humidity sensors detect changes in electrical properties (capacitance or resistance) as moisture in the air changes.
  - Soil/moisture sensors measure how well the soil conducts electricity, which increases with water content.
- **What happens when moisture increases:**
  - Air humidity sensor: capacitance or resistance changes → stronger signal.
  - Soil sensor: conductivity increases → more current flows.



Actuators

- Actuators allow for a circuit to interact with the environment by converting energy (often electrical, hydraulic, or pneumatic) into mechanical motion

- **Input:**
  - **Energy Source:** Provides the power needed for motion (e.g., electricity, compressed air, or hydraulic fluid).
  - **Control signal:** Determines the actuator's operation, often coming from a control system (e.g., microcontroller, PLC).

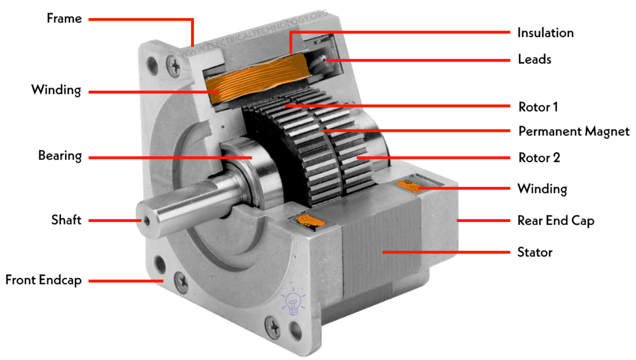
- **Output**: Actuators give a mechanical output which is the motion generated by the actuator, such as linear or rotational movement.

Actuators Outputs

- **Linear Actuators**: Produce straight-line motion (e.g., hydraulic pistons, lead screw actuators).
- **Rotary Actuators**: Produce rotational motion (e.g., motors, rotary solenoids).
- **Combination Actuators**: Use mechanisms like cams or gears to combine motions.

Electric Actuators - Motors

- **Purpose:** Convert electrical energy into mechanical movement (rotation or motion).
- **How they work:** When an electric current flows through a coil inside a magnetic field, it produces a force (the motor effect) that makes the shaft turn.
- **Common Types:**
  - DC Motors – simple, rotate when powered; speed changes with voltage.
  - Stepper Motors – rotate in precise steps, useful for positioning.
  - Servo Motors – allow controlled angle or position movement.
- **What happens when voltage increases:**
  - More current flows → motor spins faster or with more torque (depending on type).

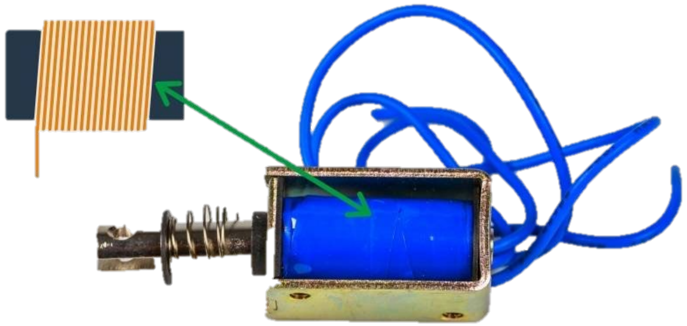


A stepper motor
Output – Rotary
Input – Power & Control Signal

An electric motor
Output – Rotary
Input – Power

Electric Actuators - Solenoid

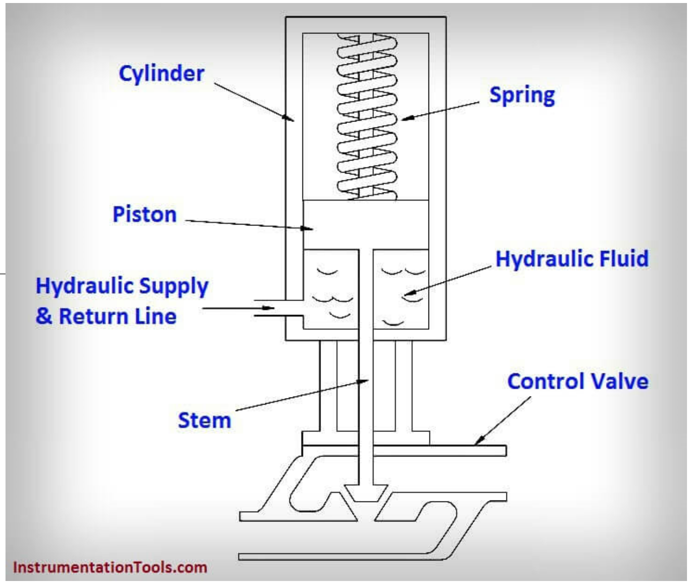
- **Purpose:** Convert electrical energy into a linear (straight-line) pushing or pulling motion.
- **How they work:** A coil of wire creates a magnetic field when current flows. This magnetic field pulls or pushes a metal rod (plunger) inside the coil.
- **What happens when voltage is applied:**
  - Current flows through the coil → magnetic field is created → plunger moves in or out.
- **Types of Solenoids:**
  - Pull-type – plunger is pulled into the coil.
  - Push-type – plunger is pushed out when activated.



An electric solenoid
Output – Linear
Input – Power

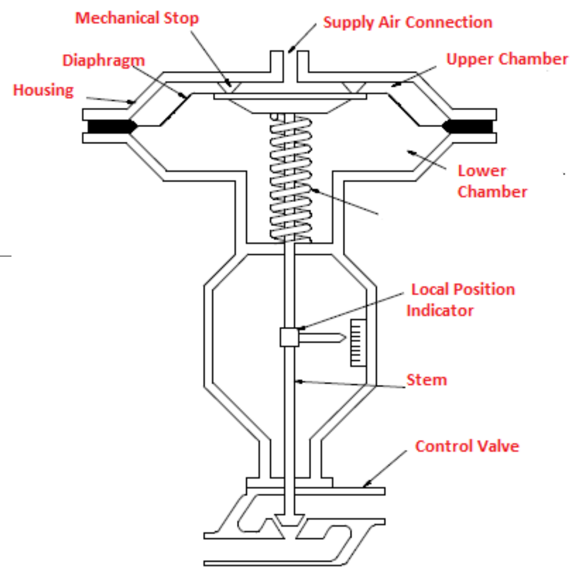
Hydraulic Actuators

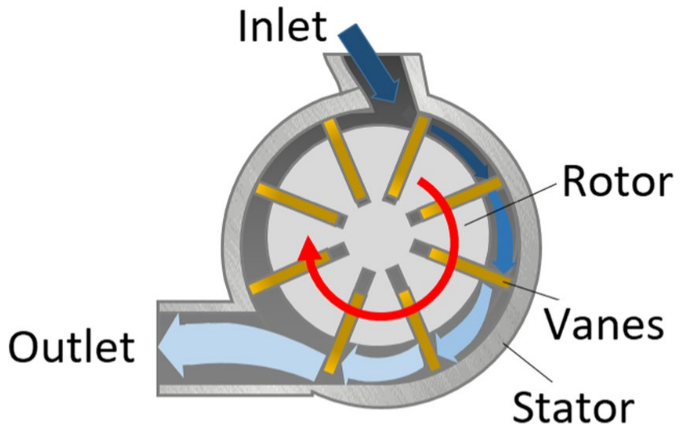
- **Purpose:** Use pressurised liquid (usually oil) to create linear or rotary movement with high force.
- **How they work:** A pump forces fluid into a cylinder or motor. The fluid pressure pushes against a piston (linear motion) or rotates a shaft (rotary motion).
- **What happens when pressure increases:**
  - More fluid pressure → greater force or torque output.
- **Types of Hydraulic Actuators:**
  - Hydraulic Cylinder – produces straight-line (linear) movement.
  - Hydraulic Motor – produces rotary motion.



Pneumatic Actuators

- **Purpose:** Use compressed air to create linear or rotary motion.
- **How they work:** Air pressure is applied to a piston inside a cylinder (for linear motion) or to a vane/rotor (for rotary motion). The expansion of compressed air pushes the actuator into movement.
- **What happens when air pressure increases:**
  - Higher pressure → stronger movement or force output.
- **Types of Pneumatic Actuators:**
  - Cylinders – provide straight-line pushing or pulling.
  - Pneumatic motors/rotary actuators – provide rotation.





Characteristics to Consider When Choosing an Actuator

- **Speed** – How quickly the actuator can move or respond.
- **Force / Torque Output** – The amount of pushing, pulling, or rotational power it can deliver.
- **Precision** – The accuracy and control of its movement (important for positioning tasks).
- **Durability & Reliability** – How well it handles wear, harsh environments, and continuous operation.
- **Energy Efficiency** – How effectively it converts input energy (electrical, hydraulic, or pneumatic) into motion.
- **Size & Weight** – Whether it fits the available space and is practical for the application.
- **Control Requirements** – How easy it is to control (simple on/off vs. fine positional control).
- **Cost & Maintenance** – Initial price and long-term upkeep needed.

Controllers

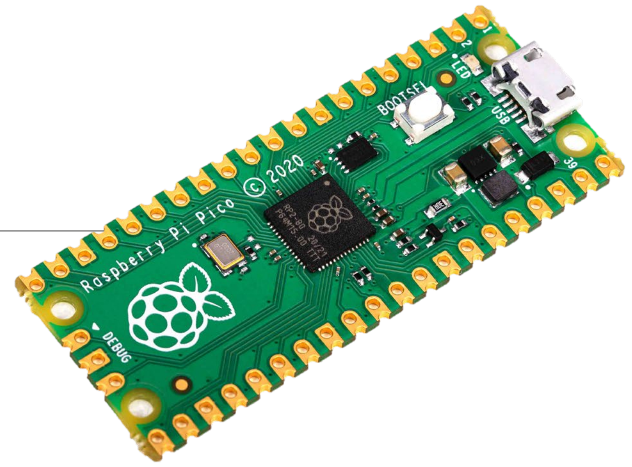
- Programmable Logic Controllers (PLCs) and microcontrollers are both used for automation and control, but they differ significantly in design, application, and functionality.

- They connect both sensors and actuators allowing for:
  - Better control of actuators movements
  - Processing of sensor input

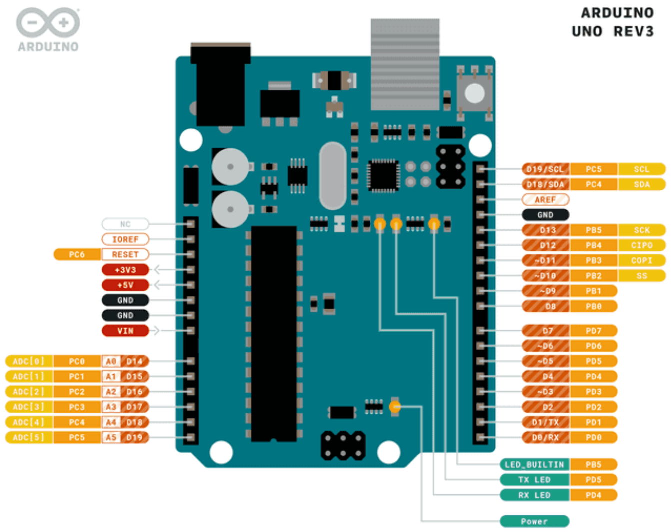
PLCs

- **Purpose:** Industrial computers used to control machinery and processes in automation systems.
- **How they work:** Continuously read signals from sensors (inputs), make decisions based on programmed logic, and send commands to actuators (outputs).
- **Key Features:**
  - Rugged Design – withstands vibration, extreme temperatures, and electrical noise.
  - Inputs & Outputs (I/O) – connect to a wide range of digital and analogue devices.
  - Programming – commonly use ladder logic diagrams, designed to be easy for engineers and technicians to understand.
  - Real-Time Operation – process inputs and update outputs instantly to keep systems running smoothly.

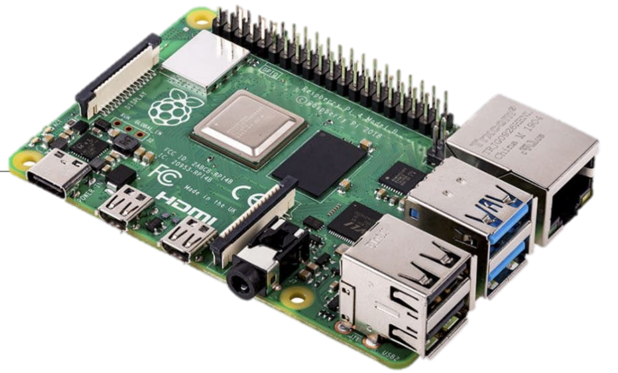
Microcontrollers



- **Purpose:** Small integrated circuits that control specific tasks in embedded systems.
- **How they work:** Contain a processor, memory, and I/O ports all on a single chip, allowing them to read sensors, process data, and control actuators directly.
- **Key Features:**
  - Compact & Lightweight – designed for single-purpose or dedicated applications.
  - Integrated Components – CPU, RAM, ROM/Flash, and input/output ports in one device.
  - Programming – commonly programmed in C/C++, Python, or Assembly.
  - Power Efficient – ideal for portable or battery-powered devices.

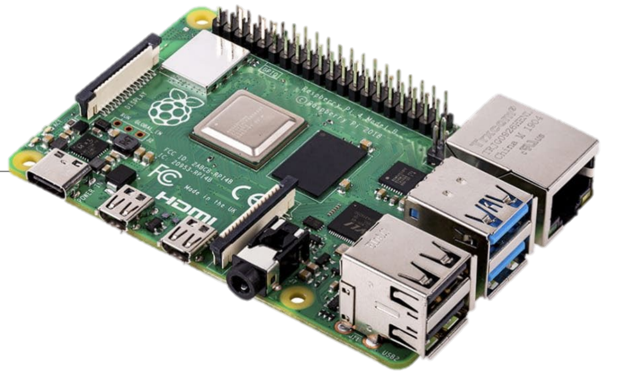


Microcomputers



- **Purpose:** General-purpose computers built around a microprocessor, designed to perform many tasks and run complex software.
- **How they work:** Contain a processor, memory, storage, and input/output interfaces. Unlike microcontrollers, they run full operating systems and can handle multiple applications.
- **Key Features:**
  - Versatile – capable of multitasking and running advanced programs.
  - Operating Systems – typically run Linux, Windows, or other OS software.
  - Connectivity – support USB, HDMI, Wi-Fi, Bluetooth, and networking.
  - Expandable – allow add-ons like external storage, displays, and sensors.

Microcomputers



- **Purpose:** General-purpose computers built around a microprocessor, designed to perform many tasks and run complex software.
- **How they work:** Contain a processor, memory, storage, and input/output interfaces. Unlike microcontrollers, they run full operating systems and can handle multiple applications.
- **Key Features:**
  - Versatile – capable of multitasking and running advanced programs.
  - Operating Systems – typically run Linux, Windows, or other OS software.
  - Connectivity – support USB, HDMI, Wi-Fi, Bluetooth, and networking.
  - Expandable – allow add-ons like external storage, displays, and sensors.

Computers

- **Purpose:** General-purpose machines designed to run a wide range of applications for work, communication, and entertainment.
- **How they work:** Use a central processing unit (CPU), memory, storage, and input/output devices to process data and execute programs under an operating system.
- **Key Features:**
  - Powerful Processing – handle complex tasks and multitasking with ease.
  - Operating Systems – run software such as Windows, macOS, or Linux.
  - User Interfaces – include monitors, keyboards, and mice for interaction.
  - Connectivity – support Wi-Fi, Bluetooth, USB, and networking for flexibility.

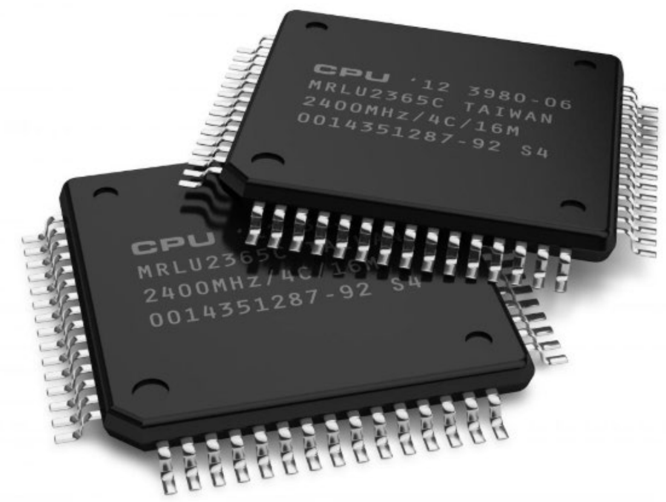
Picking a Controller

- **Application Type** – Is it industrial automation, an embedded device, or a general-purpose computer task?
- **Environment** – Does it need to withstand heat, dust, or vibration? (→ PLCs are rugged.)
- **Complexity of Task** – Simple, single-purpose control (→ Microcontroller) vs. multitasking with an OS (→ Microcomputer/Regular Computer).
- **Inputs/Outputs (I/O)** – How many sensors/actuators must be connected?
- **Real-Time Requirements** – Does it need instant response (→ PLC or Microcontroller)?
- **Cost & Power** – Is low cost/low power essential (→ Microcontroller), or is performance more important (→ PC or Microcomputer)?

Controller Comparison

Feature	**Microcontrollers (MCU)**	**Microcomputers**	**PLCs**
Purpose	Control **single, specific tasks** in embedded systems	Run **operating systems** and handle multiple applications	Control **industrial machinery & processes**
Hardware	CPU, RAM, ROM, I/O all on one chip	CPU, RAM, storage, OS support (like a mini PC)	Rugged CPU with large I/O modules
Programming	C, C++, Python, Assembly	Python, C, C++, Linux-based languages	Ladder Logic, Function Block, Structured Text
Environment	Small devices, portable, low-power	Education, robotics, IoT hubs, general-purpose	Harsh industrial environments
I/O Capability	Limited pins, direct sensor/actuator control	Many ports (USB, HDMI, GPIO), expandable	Large digital & analogue I/O capacity
Applications	Appliances, wearables, IoT devices	Robotics, AI, education projects	Factory automation, production lines, safety systems

Microprocessor



- **Purpose:** The “brain” of a computer – a chip that processes instructions and performs calculations.
- **How they work:** Contain only the CPU (Central Processing Unit), which fetches, decodes, and executes instructions. Unlike microcontrollers, they do not include built-in memory or I/O ports.
- **Key Features:**
  - High Processing Power – capable of handling complex programs and multitasking.
  - Requires External Components – needs RAM, storage, and I/O chips to form a complete computer.
  - Versatile – used in general-purpose computing, from PCs to servers.
  - Runs Operating Systems – such as Windows, Linux, macOS.