ME-410: Introduction to Microcontroller Applications in Robotics

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What is Microcontroller?

Definition:

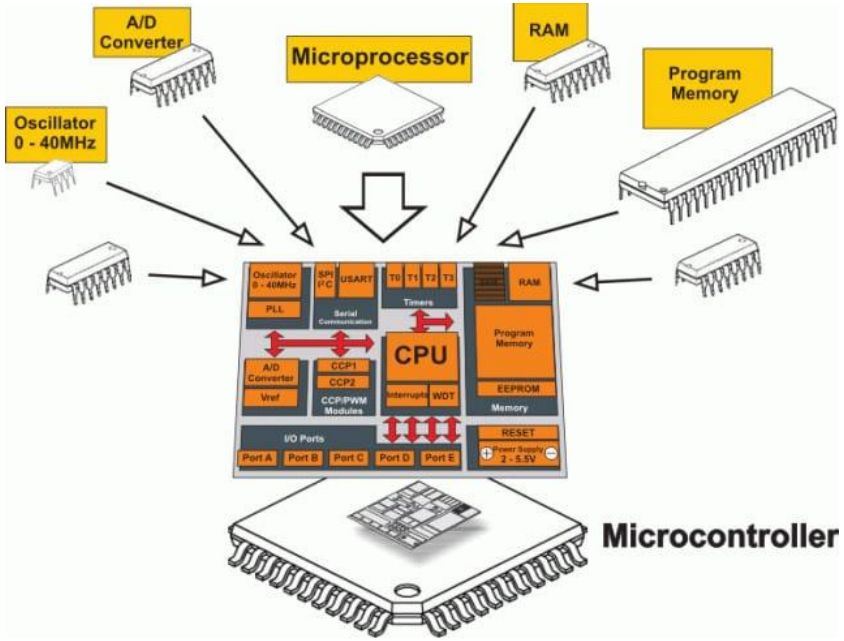
A compact integrated circuit designed to govern a specific operation in an embedded system.

Components:

- Processor
- memory
- input/output pins
- On-chip peripherals

Why do we use microcontrollers?

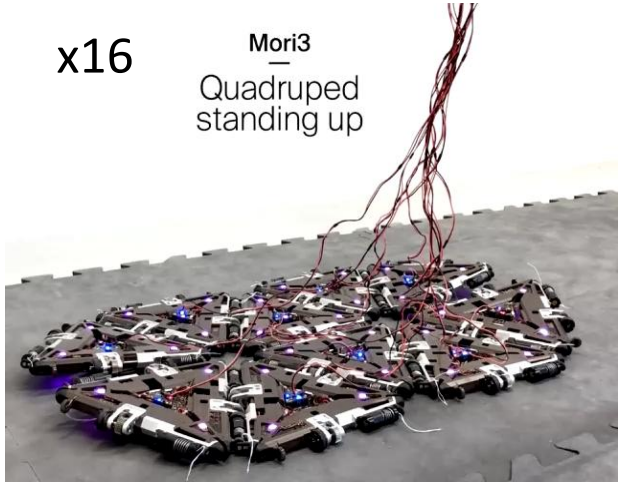
- Size and portability
- Power consumption
- Real-time Operation



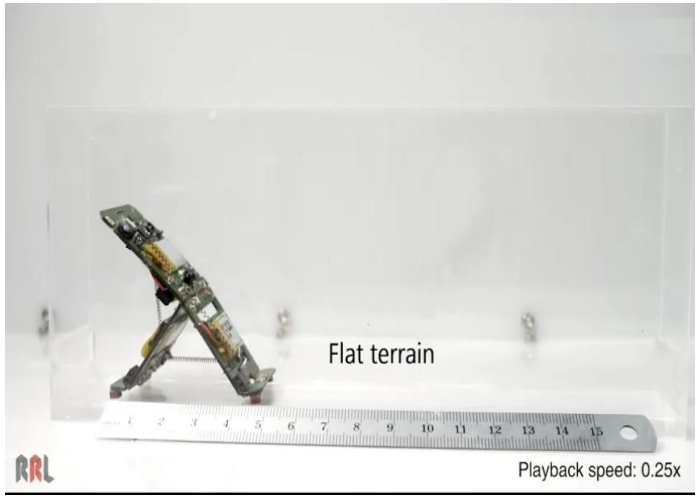
Source: Max Embedded

Why Microcontrollers in Robotics?

- Small and portable
- Low power consumption
- Real-time operation
- Bridge between sensors and actuators
- Core of embedded robotic intelligence



RRL, Nature MI 2023



RRL, Nature 2019

Source: crazyflie 2.0

Source: ODrive

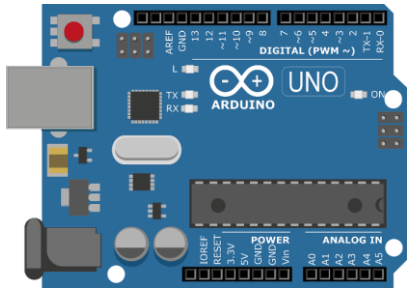
Source: openMV

Microcontroller Platforms Today

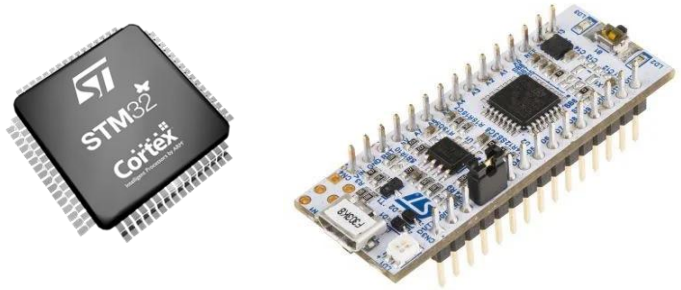
- There are many microcontrollers available today, ranging from industrial-grade systems to hobbyist-friendly platforms.

- Popular choices for prototyping and robotics include:
  - Arduino: Beginner-friendly, open-source ecosystem
  - ESP32: High performance, built-in wireless features
  - STM32: Industrial-grade performance, wide performance range

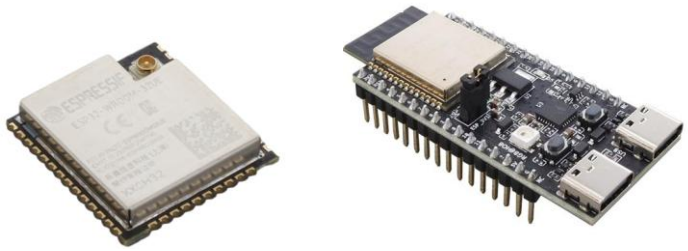
- In this course, we focus on Arduino (and optionally ESP32) for hands-on learning and accessibility.



Arduino



STM32



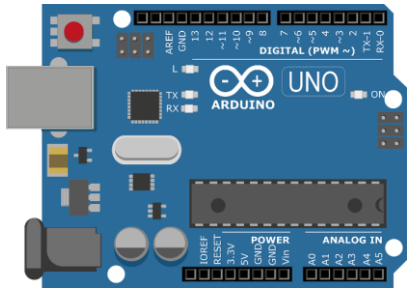
ESP32

What is Arduino?

Open-source hardware and software company that designs and manufactures **single-board microcontrollers**

Code and designs files are accessible by anyone!

- No “black box” = more control
- Completely free
- Don’t rely on a company
- Active and large community



ARDUINO

Provides all of the circuitry necessary for a useful control task: a microprocessor, I/O circuits, a clock generator, RAM, stored program memory and any necessary support ICs.

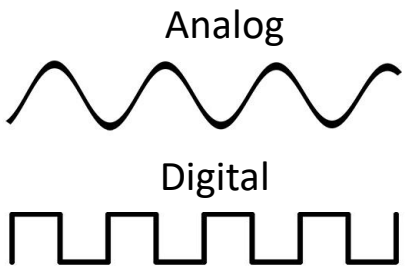
Arduino in ME-410

Inputs

User

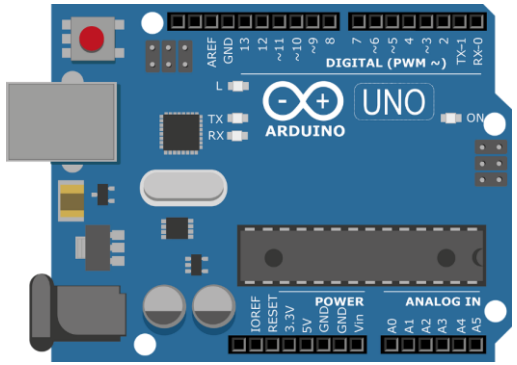
Sensors

Signals



Programming

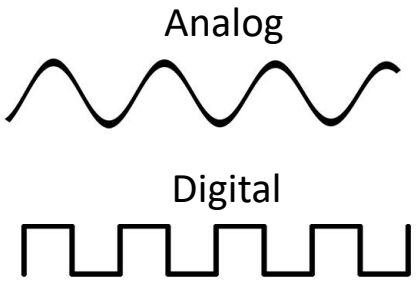
Reading



Outputs

Actuators

Indicators



Signals

Arduino can interact with electronic components to control your robot

Choose your board

Features	Specs	Integration	Sensors
• ADCs • DACs • GPIO • Wifi • Bluetooth • …	• Clock speed • Memory • Interrupts • Power consumption • …	• Size • Weight • Input voltage • Output voltage • Output current • …	• Gyro • Accel • Magnetometers • Gesture • Humidity • Sound • …

Official arduino board

Variety of Features, Specs and Integrations capabilities

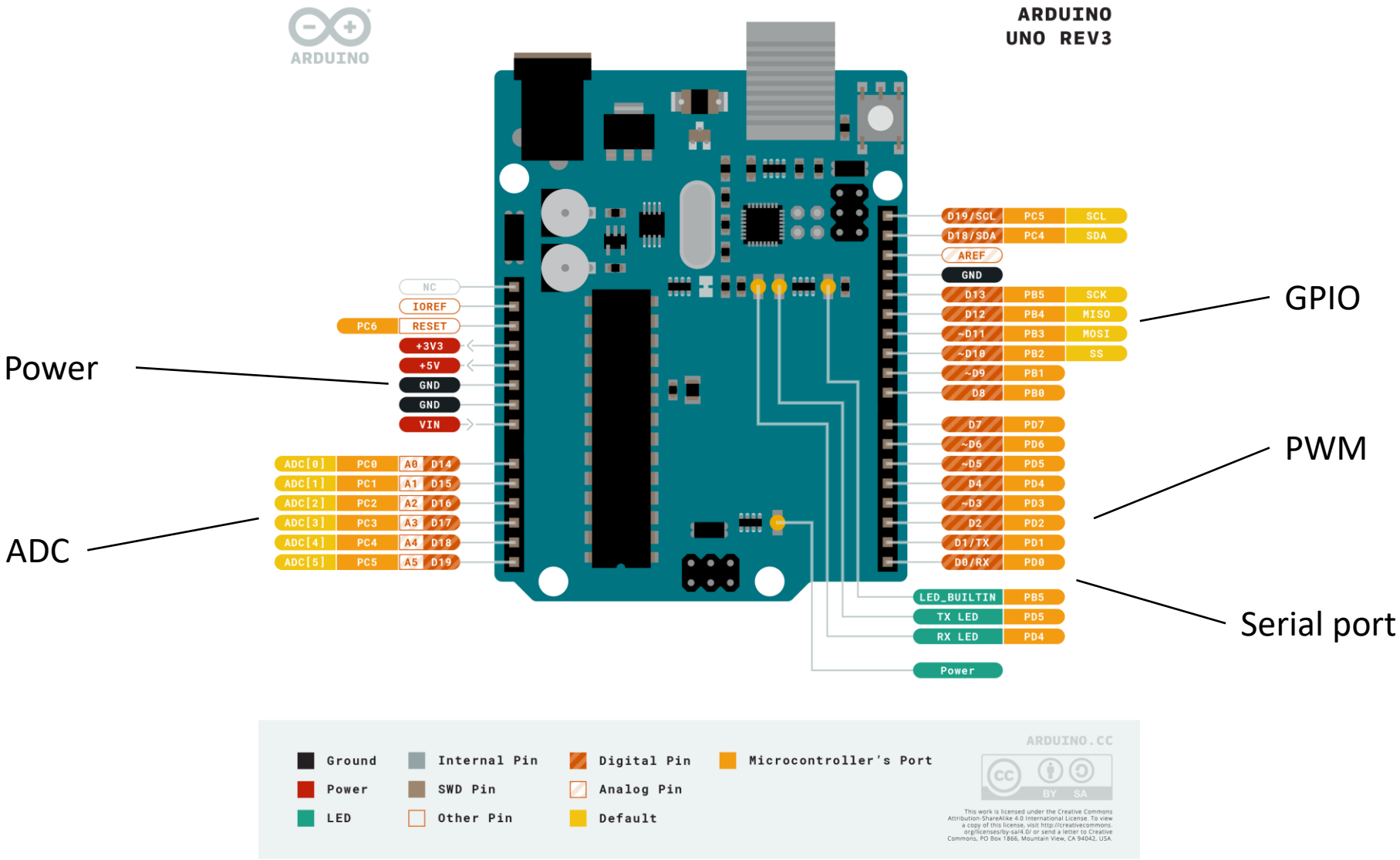
Teensy

Small and powerful Arduino-like development board

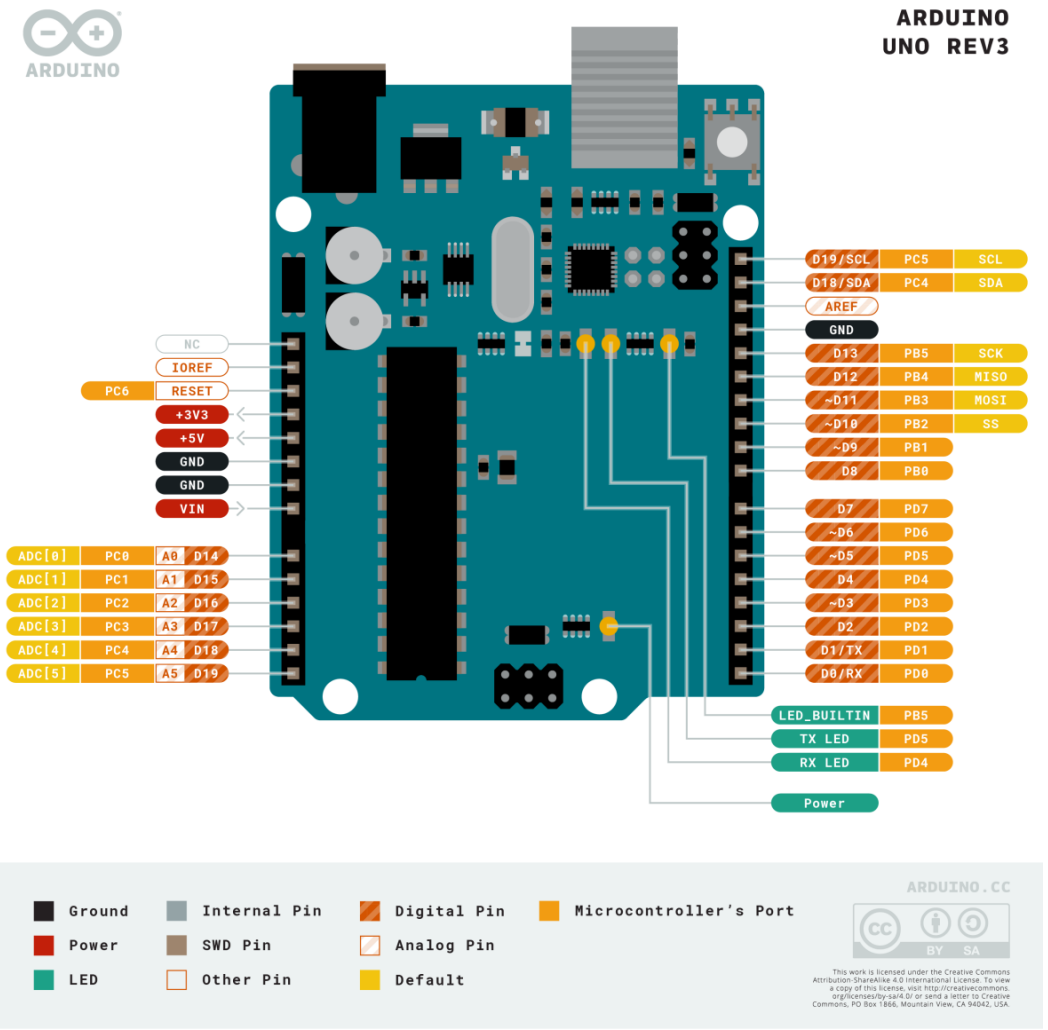
ESP/ STM32 with Arduino framework

Variety of Features, Specs and Integrations capabilities

Arduino Uno Pinout



Arduino Features

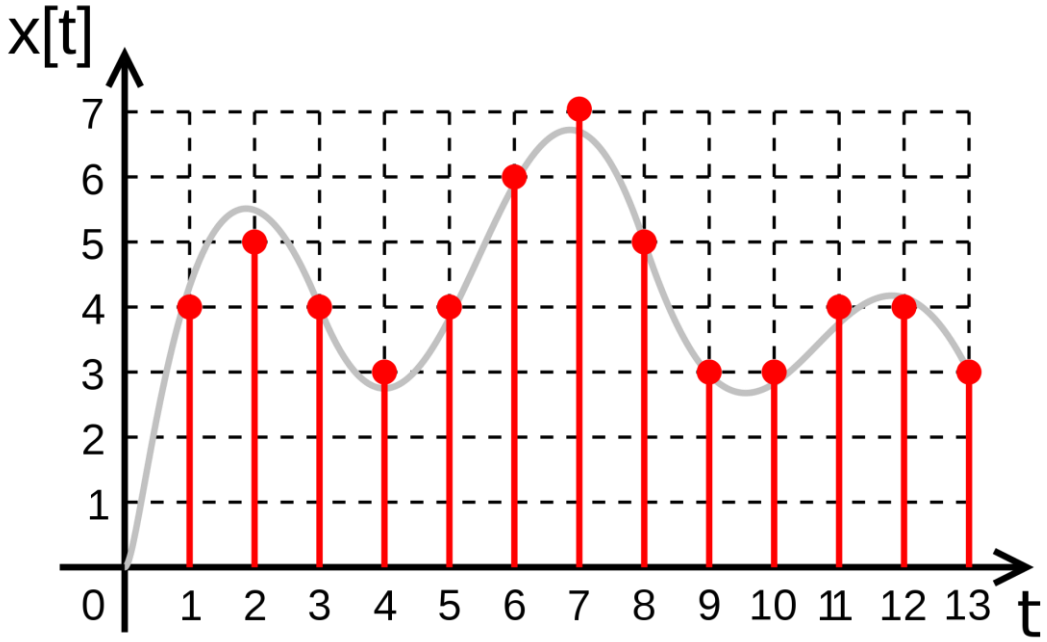


Features:

- ADC
- UART (serial interface)
- Interrupts
- PWM
- GPIO
- …

Analog to Digital Converter

ADC, or Analog-to-Digital Converter, translates analog signals into digital values for microcontrollers like Arduino to read.



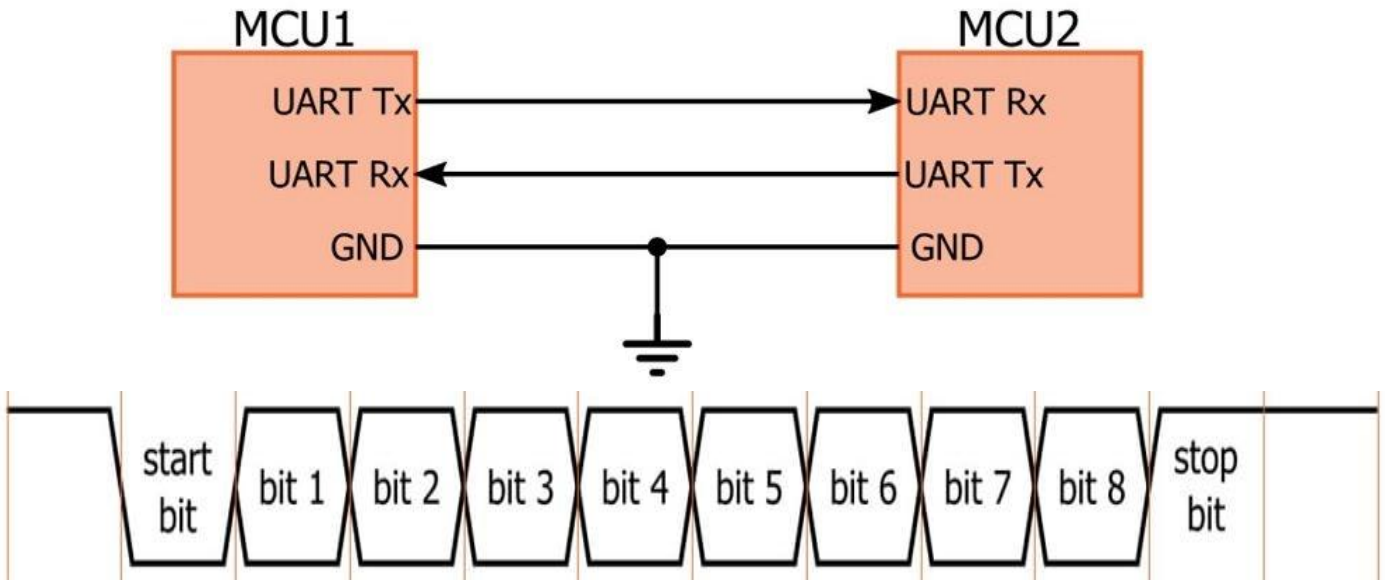
$$Voltage = ADC\ reading \times \frac{Arduino\ voltage}{ADC\ Resolution}$$

5V for Uno

$2^n - 1$ with n the ADC bits

Universal Asynchronous Reception and Transmission(UART)

UART (Universal Asynchronous Receiver/Transmitter) is a hardware communication protocol used for asynchronous serial communication between devices.



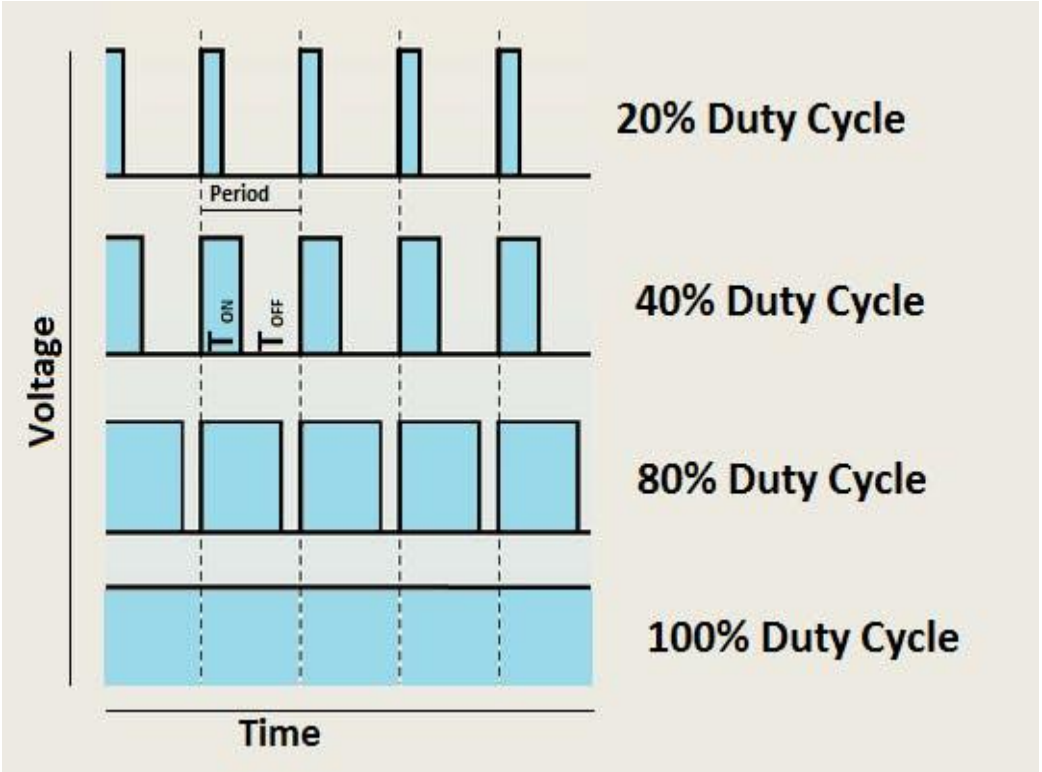
Key Terms

- **Start bit:** The first bit of a one-byte UART
- **Stop bit:** The last bit of a one-byte UART transmission.
- **Baud rate:** The approximate rate (in bits per second, or bps) at which data can be transferred.

Pulse Width Modulation (PWM)

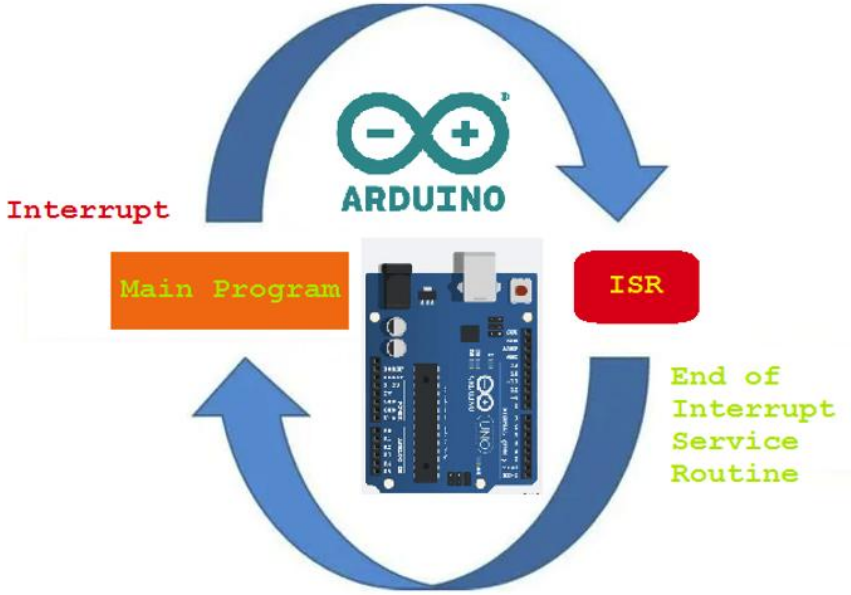
PWM stands for Pulse Width Modulation and it is a technique used in controlling the brightness of LED, speed control of DC motor, controlling a servo motor or where you have to get analog output with digital means.

- **TON (On Time):** It is the time when the signal is high.
- **TOFF (Off Time):** It is the time when the signal is low.
- **Period:** It is the sum of on time and off time.
- **Duty Cycle:** It is the percentage of time when the signal was high during the time of period.



Interrupts

- **What is an Interrupt?**
  - A signal to the CPU to pause and handle external events, enhancing real-time responsiveness and computational efficiency.
- **Key Concepts**
  - **Types**: Hardware and Software Interrupts.
  - **Purpose**: Ensure timely system responses and allow multitasking during I/O operations.
  - **Usage:** Employed to handle tasks like responding to a button press, receiving data, or managing timed events in embedded systems.



Arduino Uno specifications

Specs are available on the [arduino store]

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA

Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Select the peripherals based on microcontroller specifications

Arduino Uno

DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V

ECON Servo-180°

Dimensions	40.8*20.1*38mm
Product Weight	44g
Output Shaft Style	25T
Angle Rotation	180 degree
Voltage Range	4.8~7.2 Volts
No-Load Speed(6.0V)	0.19sec/60°
No-Load Speed(4.8V)	0.23sec/60°
Stall Torque(6.0V)	4.1kg.cm
Stall Torque(4.8V)	3.2kg.cm
Max PWM Signal Range(Standard)	500~2500usec
Travel per μs(out of box)	/
Max Travel(out of box)	/
Pulse Amplitude	3~5V
Operating Temperature	(-)10 to +50 degree C
Current Drain -idle(6.0V)	20mA
Current Drain - no-load(6.0V)	200mA

Select your sensors based on microcontroller specifications

What is the robot current configuration ?
- Joints position
- Speed
- Power consumption
- Heat

What is applied on the environment ?
- Force
- Contact

Localise the robot:
- GPS
- Vision

Interact:
- With the environment (ex: move an object)
- With the human (ex: assistive Robotics)

Robotic sensors are used to estimate a robot's condition and environment. These signals are passed to a controller to enable appropriate behaviour.

Most of the time, the controller is an algorithm implemented on a microcontroller (ex: Arduino) that controls the actuators depending on the sensor data

Arduino sensors

Select your sensors based on microcontroller specifications

By working principle:

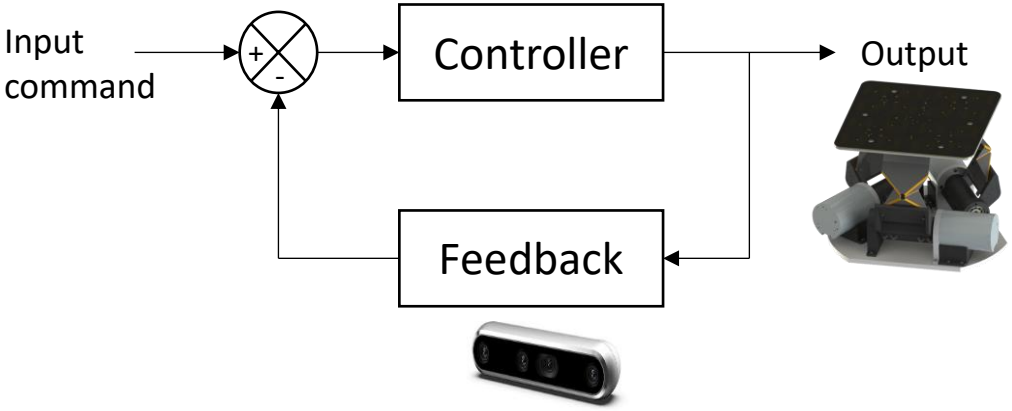
- Resistive
- Capacitive
- Magnetic
- Optical
- MEMS
- Sound
- …

By function:

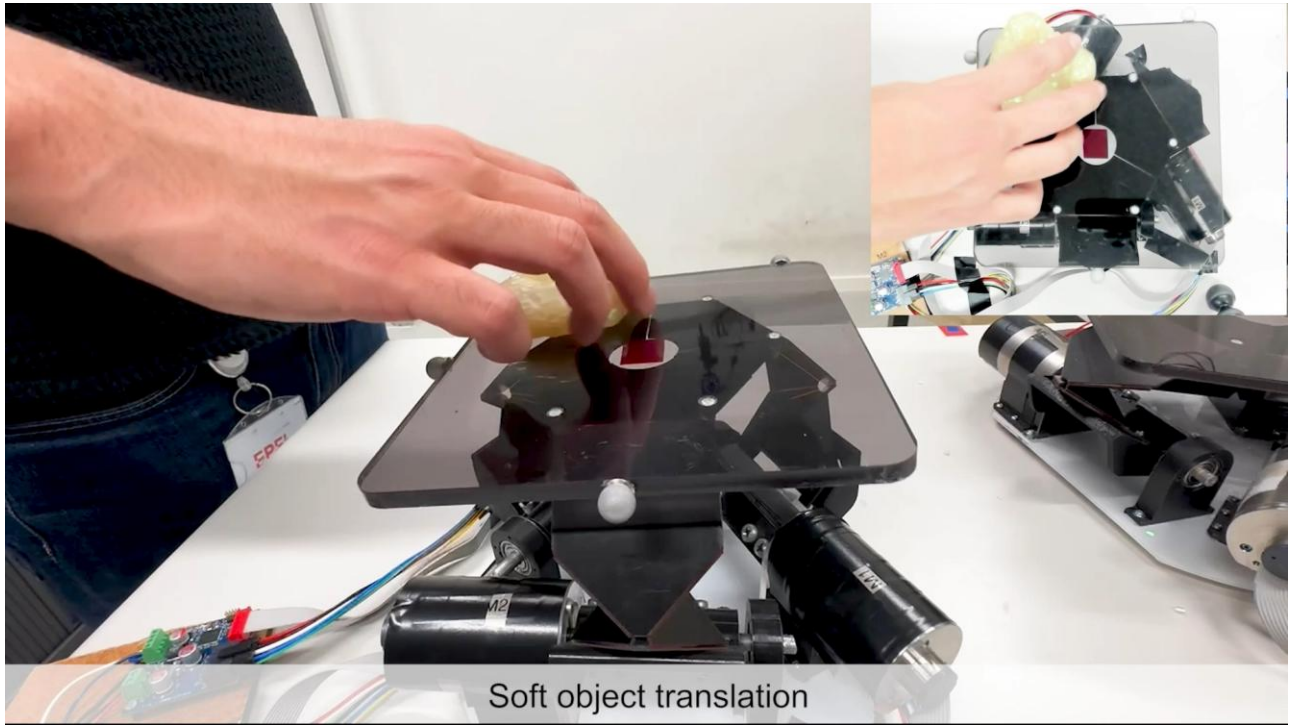
- *Vision and Imaging Sensors*
- *Temperature Sensors*
- *Radiation Sensors*
- *Proximity Sensors*
- Position Sensors
- Motion Sensors
- *Photoelectric Sensors*
- *Particle Sensors*
- *Metal Sensors*
- *Pressure Sensors*
- *Level Sensors*
- *Leak Sensors*
- *Humidity Sensors*
- *Gas and Chemical Sensors*
- Force Sensors
- *Flow Sensors*
- *Flaw Sensors*
- *Flame Sensors*
- *Electrical Sensors*
- Contact Sensors
- *Non-Contact Sensors*

By return values : digital or analog

Application example

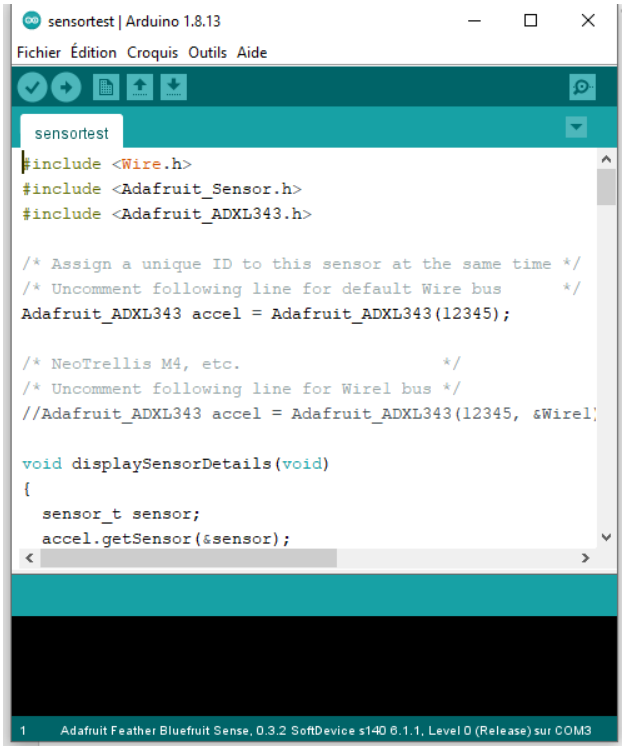


- Camera give the object's position
- Control algorithm running on the microcontroller calculates the target position for each motor.
- Motors' relative rotation angles with encoders



Basics in Arduino programming: IDE

[Download basic usual IDE]



Pros:

- Perfect for beginners
- Easy to use
- Great Serial plotter
- GUI makes it easy to change the board connection parameters

Cons:

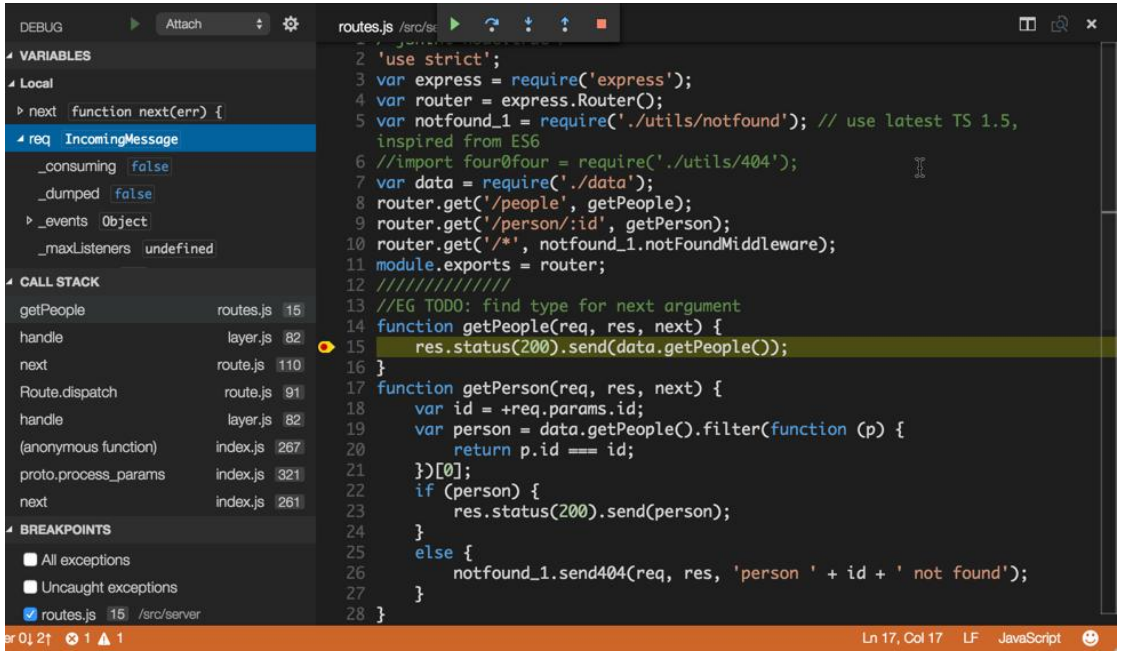
- No color highlight
- No autocomplete
- Difficult Multi-file programming
- It's like programming on a notepad

Basics in Arduino programming: IDE

[Visual studio code](#)

+

[PlatformIO](#)



Pros:

- Multi-file organisation
- Programs easily transportable
- Works with a lot of boards

Cons:

- Not as straightforward to use than the official IDE

Arduino is C++

(So you can use any C++ IDE)

Basics in Arduino programming

Arduino is embedded C made easy

Arduino code must contains two functions:

Run once at the code initialization (board startup)

```
void setup(void)
{
}
```

Init

- Variables
- GPIO
- Timers
- Interrupts
- All the system parameters your program needs

Infinite loop, equivalent to while(true)

```
void loop(void)
{
}
```

Run continuously while the board is power supplied

- Read sensors
- Send control commands
- Communicate with the computer
- Contains the program logics

Basics in Arduino programming

Example

Declare variables as global (variables declared inside a function are deleted when the function ends)

```
/*
  DigitalReadSerial

  Reads a digital input on pin 2, prints the result to the Serial Monitor

  This example code is in the public domain.
 http://www.arduino.cc/en/Tutorial/DigitalReadSerial
*/
```

```
// digital pin 2 has a pushbutton attached to it. Give it a name:
int pushButton = 2;

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
  // make the pushbutton's pin an input:
  pinMode(pushButton, INPUT);
}
```

```
// the loop routine runs over and over again forever:
void loop() {
  // read the input pin:
  int buttonState = digitalRead(pushButton);
  // print out the state of the button:
  Serial.println(buttonState);
  delay(1);       // delay in between reads for stability
}
```

Lots of examples are available under *File* -> *Examples* In the Arduino IDE

Basics in Arduino programming

Functions

Please look at the datasheet before using built-in functions

Declaration →

```
void customFunction(char inputVariable);

void setup(void)
{
  Serial.begin(9600)
}

void loop(void)
{
  customFunction('a');
}

void customFunction(char inputVariable){
  Serial.println(inputVariable);
}
```

Call →

Function body →

Demo: Controlling a Servo Motor with Serial and Interrupt

Objective:

- Use Serial Monitor to send commands (0–9) to control servo angle
- Use external interrupt (button) to reset servo to 0°

Hardware Setup:

- Servo: connected to pin 9 (PWM)
- Button (interrupt): connected to pin 2, active low
- Power: USB or 5V regulated
- Serial: 9600 baud rate