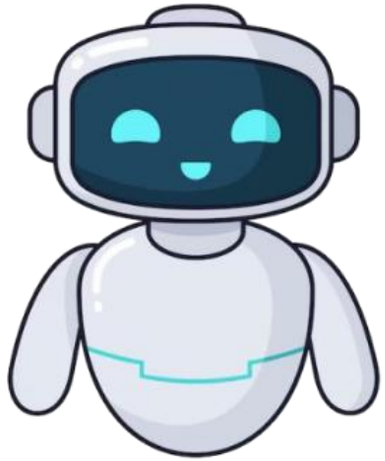
Advanced Arduino Course



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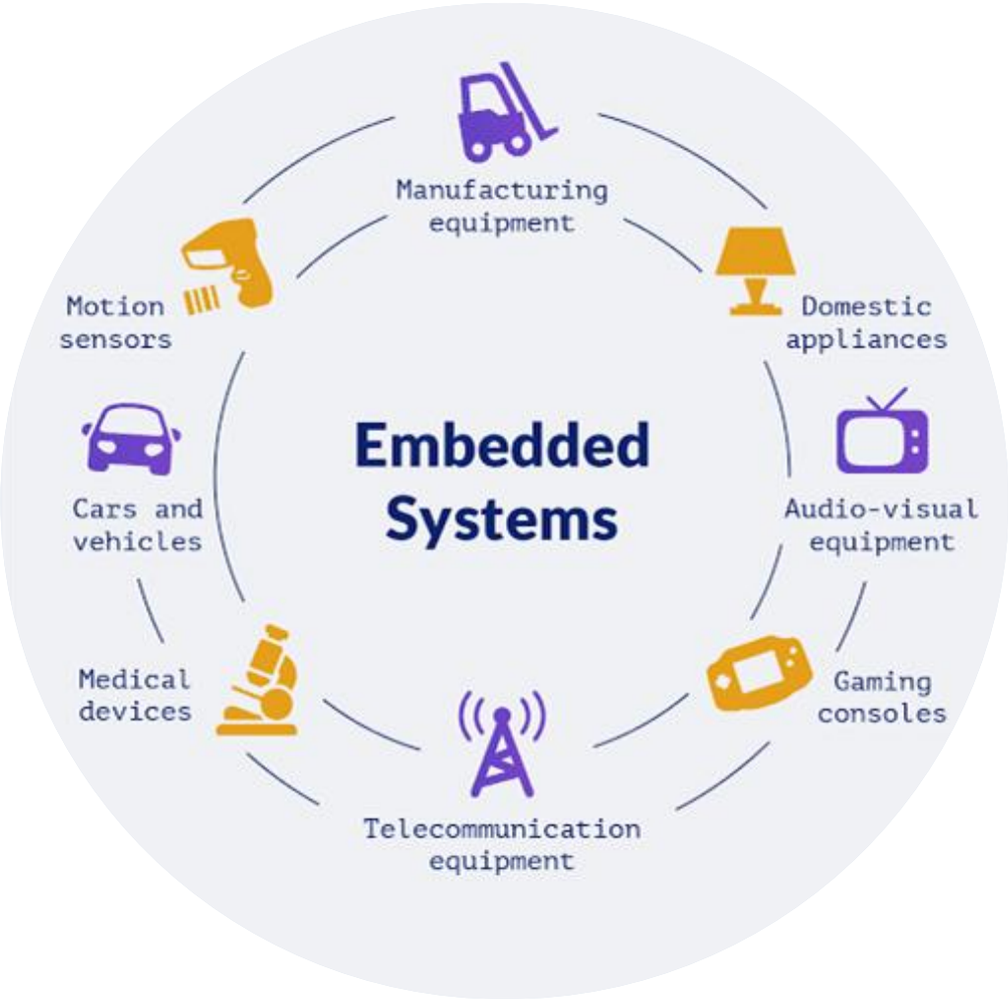
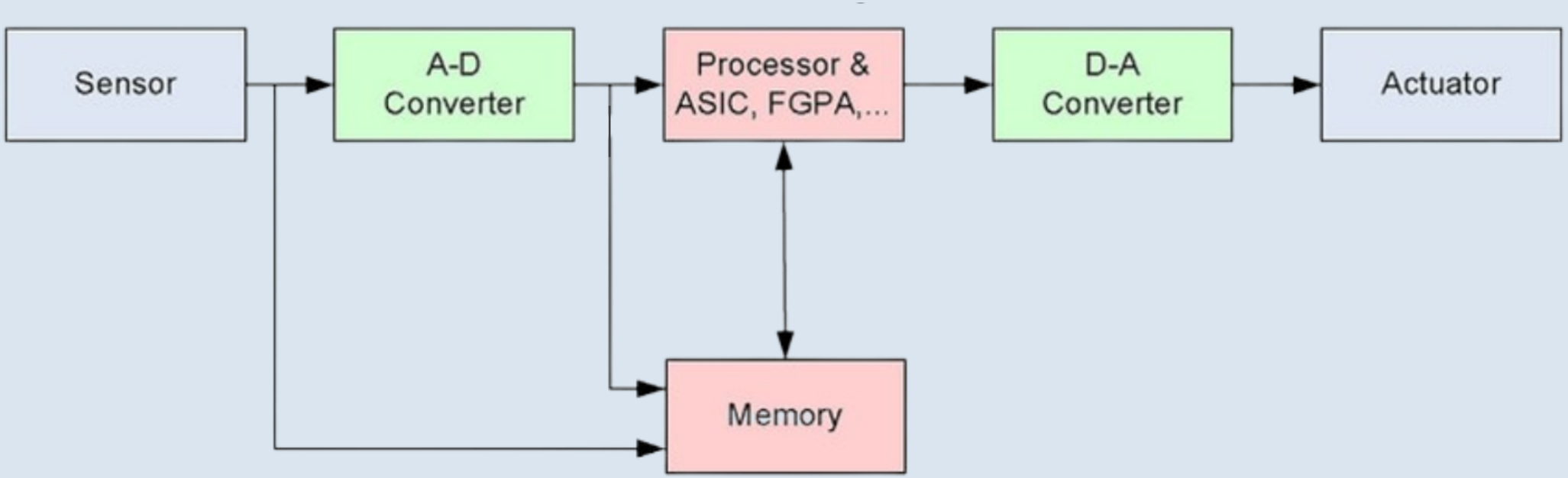
IEEE Robotics and Automation Society

Introduction



Embedded systems (Symbolic-Based)



Arduino Hardware

Arduino Boards

- Microcontroller-based boards with various input/output capabilities.
- Examples: Arduino Uno, Arduino Mega, Arduino Nano.

Key Components

- **Microcontroller**: The brain of the board (e.g., ATmega328 on Arduino Uno).
- **Digital Pins**: Used for digital input/output (e.g., LEDs, buttons).
- **Analog Pins**: Used for analog input (e.g., sensors).
- **Power Supply**: Can be powered via USB or external power source.
- **Communication Ports**: Serial, I2C, SPI for interfacing with other devices.

ESP32 Hardware

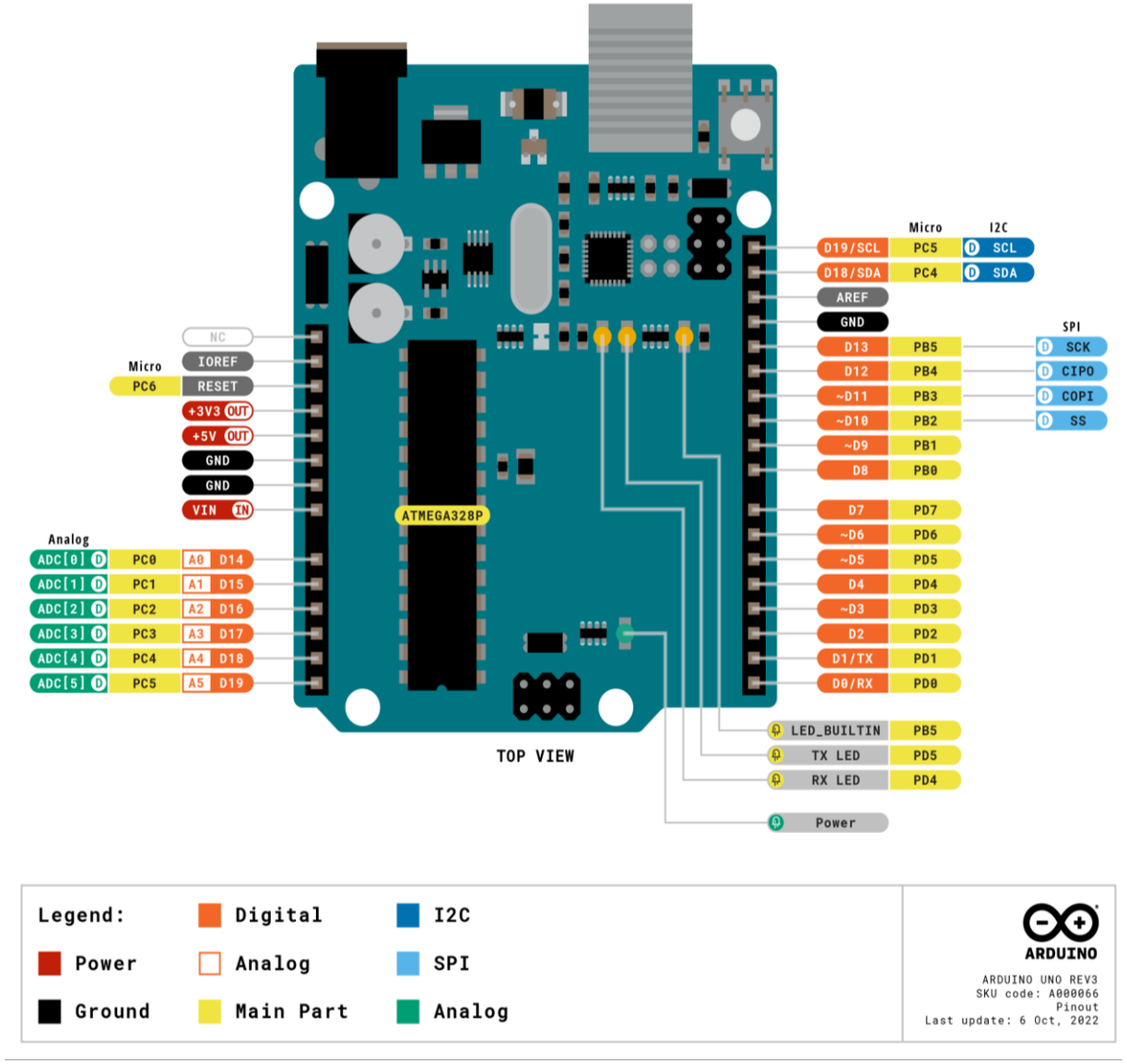
ESP32 Overview

- A low-power Wi-Fi and Bluetooth microcontroller with various input/output capabilities.
- Developed by Espressif Systems, commonly used in IoT applications.

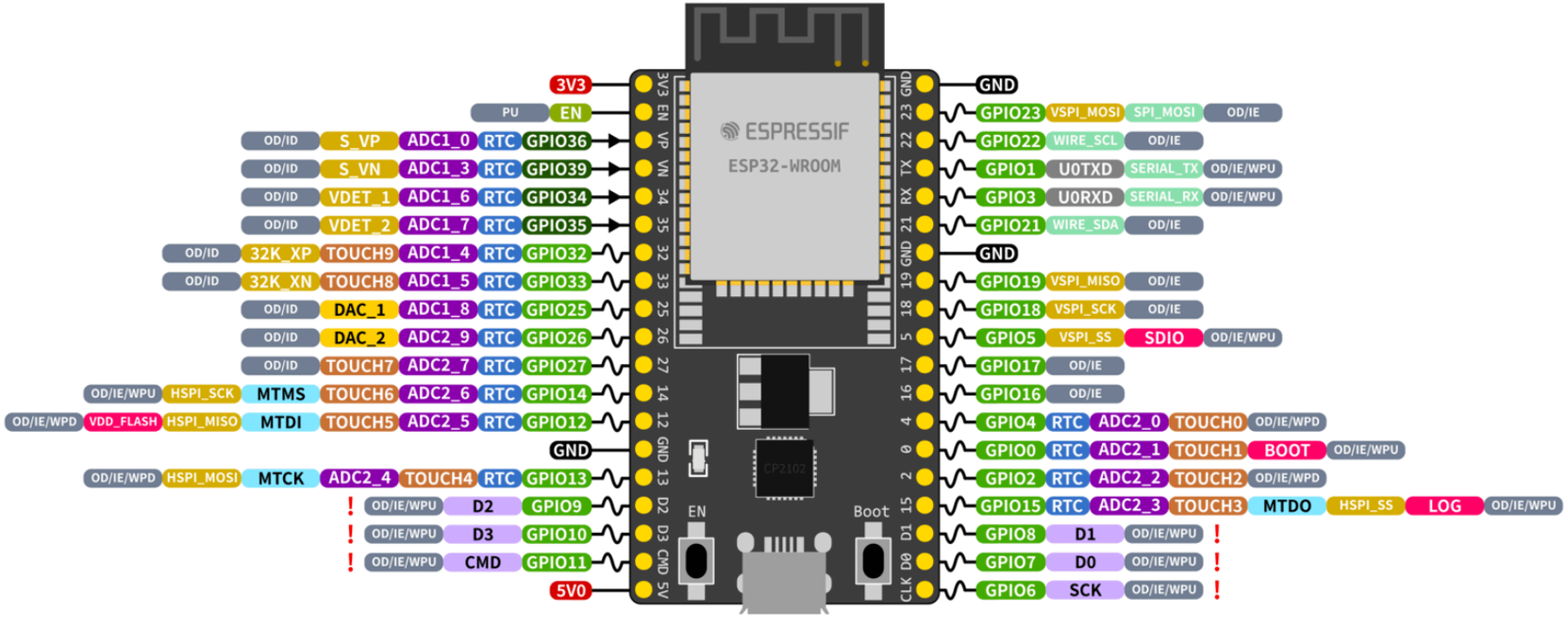
Key Components

- **Microcontroller**: Dual-core Tensilica Xtensa LX6 processor with up to 240 MHz clock speed.
- **Digital Pins**: Supports multiple GPIO pins for digital input/output operations.
- **Analog Pins**: Features ADC (Analog-to-Digital Converter) and DAC (Digital-to-Analog Converter).
- **Power Supply**: Operates at 3.3V, powered via USB or external Li-ion battery.
- **Wireless Connectivity**: Built-in Wi-Fi (802.11 b/g/n) and Bluetooth (Classic & BLE) for wireless communication.
- **Communication Ports**: Supports UART, I2C, SPI, PWM, and CAN protocols for external device interfacing.

Arduino Uno board



ESP-32 board



ESP32 Specs

32-bit Xtensa® dual-core @240MHz
Wi-Fi IEEE 802.11 b/g/n 2.4GHz
BLuetooth 4.2 BR/EDR and BLE
520 KB SRAM (16 KB for cache)
448 KB ROM
34 GPIOs, 4x SPI, 3x UART, 2x I2C,
2x I2S, RMT, LED PWM, 1 host SD/eMMC/SDIO,
1 slave SDIO/SPI, TWAI®, 12-bit ADC, Ethernet

PWM Capable Pin
GPIOX GPIO Input Only
GPIOX GPIO Input and Output
DAC_X Digital-to-Analog Converter
DEBUG JTAG for Debugging
FLASH External Flash Memory (SPI)
ADCX_CH Analog-to-Digital Converter
TOUCHX Touch Sensor Input Channel
OTHER Other Related Functions
SERIAL Serial for Debug/Programming
ARDUINO Arduino Related Functions
STRAP Strapping Pin Functions

RTC RTC Power Domain (VDD3P3_RTC)
GND Ground
PWD Power Rails (3V3 and 5V)
! Pin Shared with the Flash Memory *Can't be used as regular GPIO*

GPIO STATE

WPU: *Weak Pull-up (Internal)*
WPD: *Weak Pull-down (Internal)*
PU: *Pull-up (External)*
IE: *Input Enable (After Reset)*
ID: *Input Disabled (After Reset)*
OE: *Output Enable (After Reset)*
OD: *Output Disabled (After Reset)*

Arduino Software (use for Arduino UNO & ESP32)

Arduino IDE

- Integrated Development Environment for writing, compiling, and uploading code to Arduino boards.
- Available for Windows, Mac, and Linux.

Key Features

- **Code Editor**: Write and edit Arduino sketches (programs).
- **Compiler**: Convert sketches into machine code that the microcontroller can execute.
- **Uploader**: Transfer the compiled code to the Arduino board via USB.
- **Serial Monitor**: Communicate with the board and debug sketches using serial communication.

Programming Language

- Based on C/C++ with simplified syntax and functions.
- Uses libraries to add functionality (e.g., controlling motors, reading sensors).

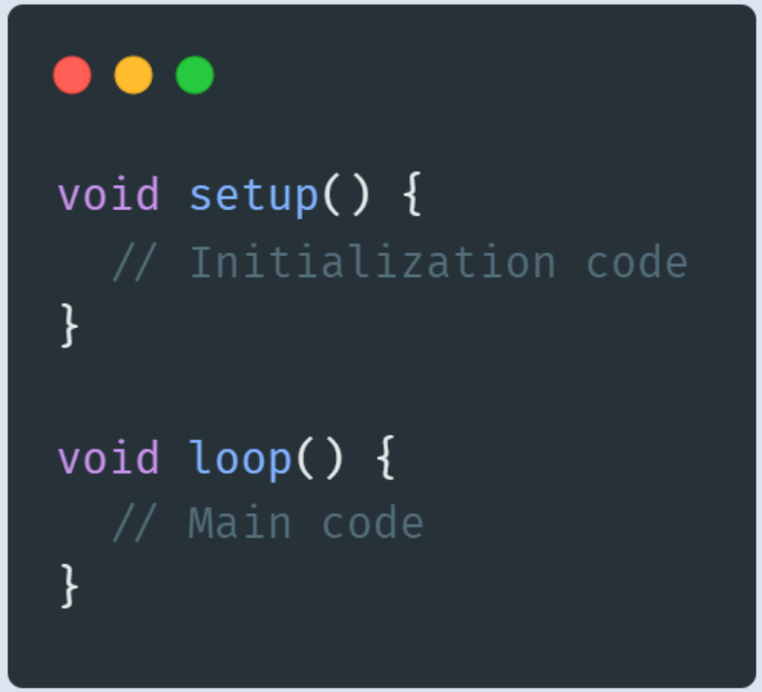
How to Program Arduino & ESP 32

Setup Function:

- **Purpose**: Initializes settings.
- **Runs Once**: This code runs once when the Arduino is powered on or reset.

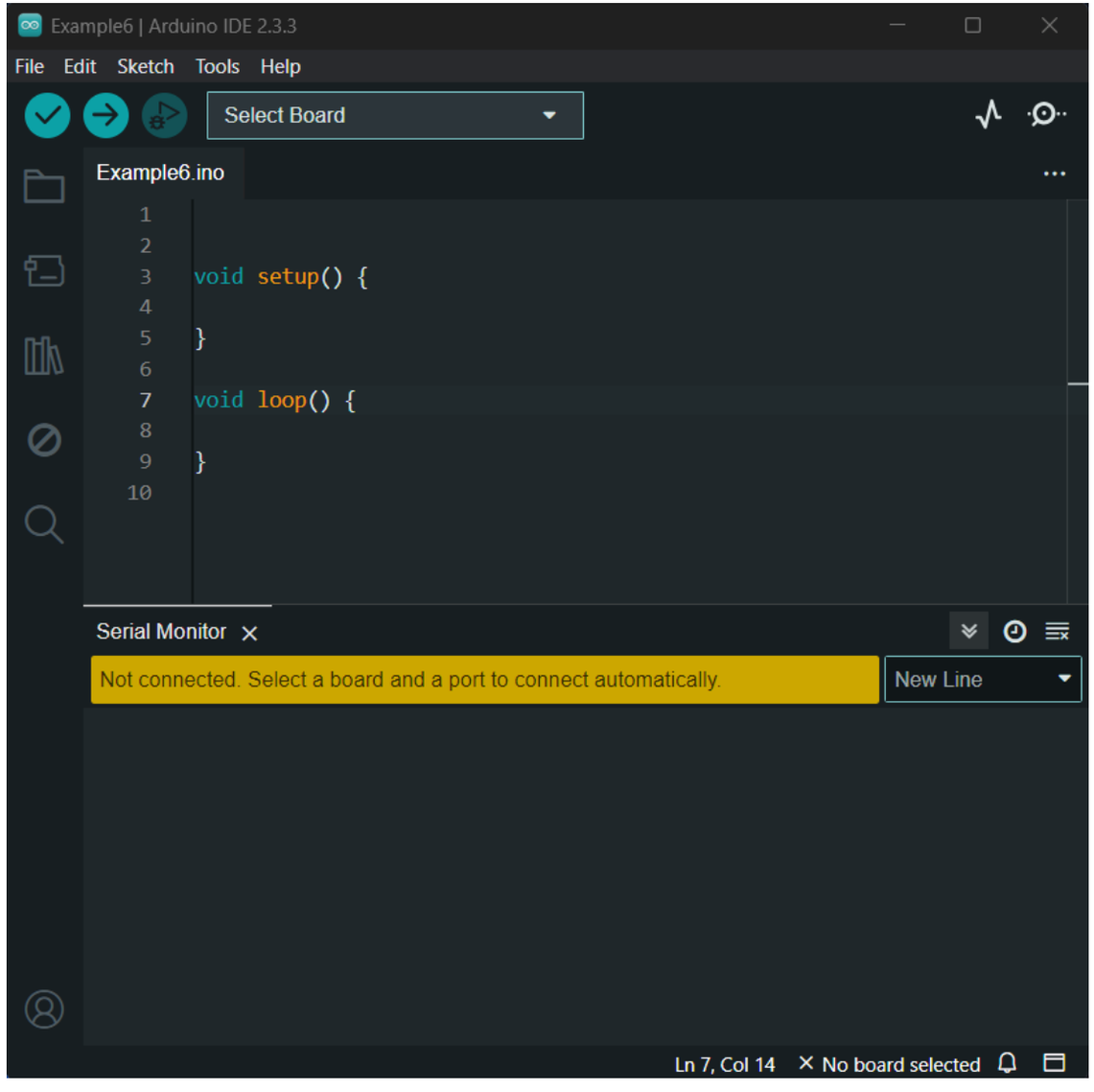
Loop Function:

- **Purpose**: Contains the main logic of the program.
- **Runs Repeatedly**: This code runs in a loop after the setup function has completed.



```
void setup() {
  // Initialization code
}

void loop() {
  // Main code
}
```

Arduino IDE simple sketch.



Common Functions Used in Arduino Programming

pinMode():

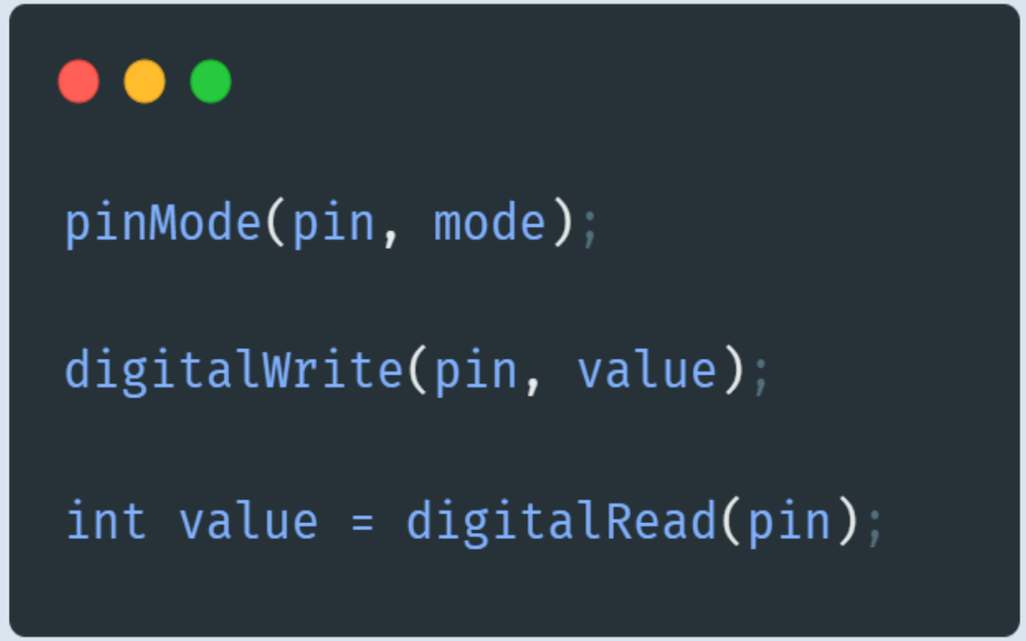
- **Purpose**: Configures a specified pin to behave either as an input or an output.

digitalWrite():

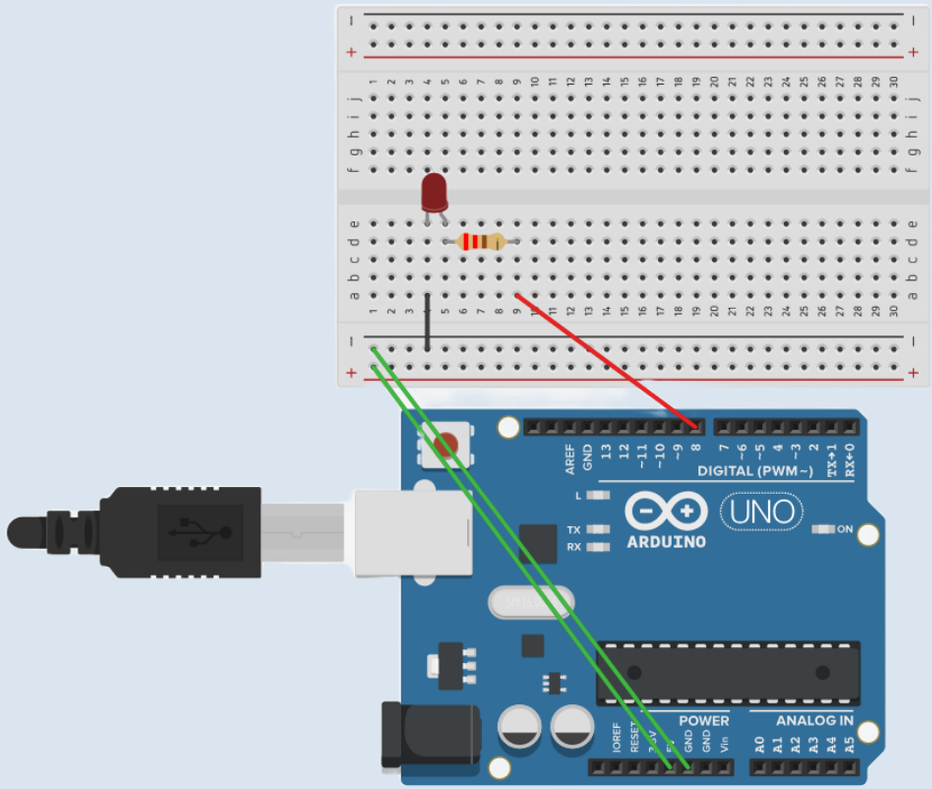
- **Purpose**: Sets a specified digital pin to HIGH or LOW.

digitalRead():

- **Purpose**: Reads the value from a specified digital pin, either HIGH or LOW.



Example:



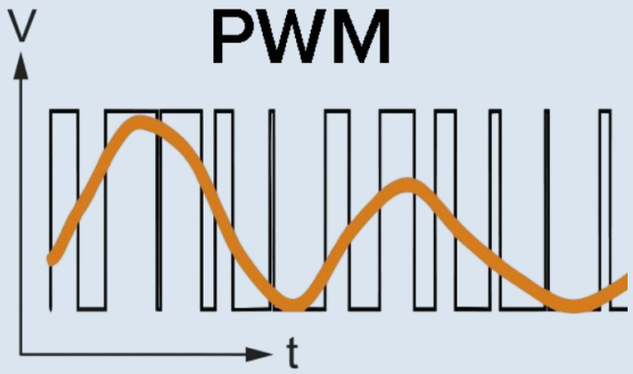
Common Functions Used in Arduino Programming

analogRead():

- **Purpose**: Reads the value from a specified analog pin.

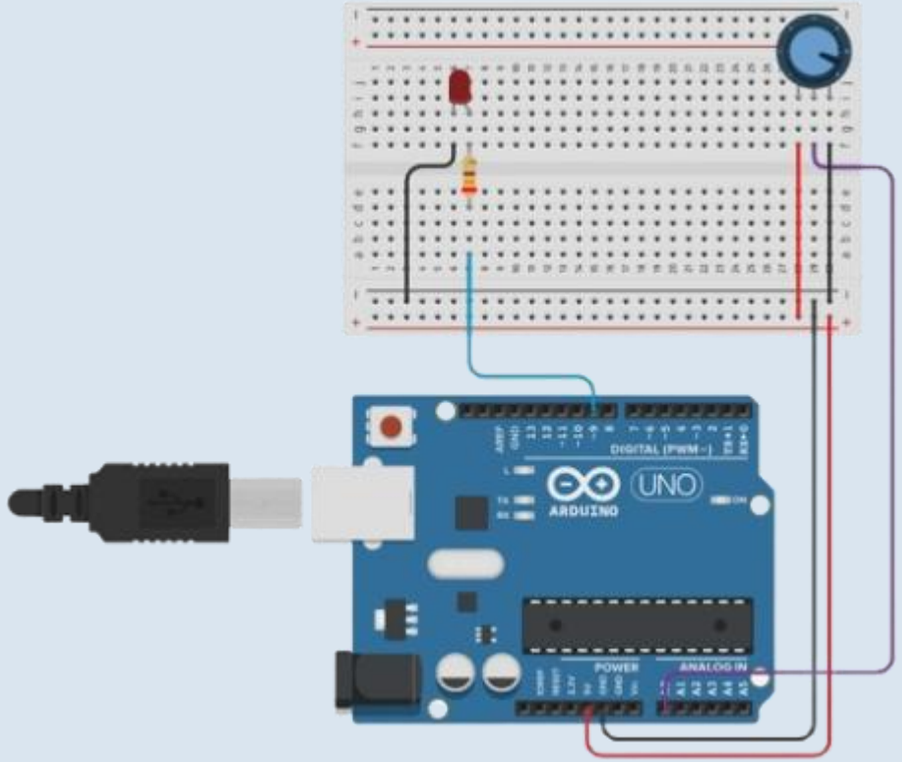
analogWrite():

- **Purpose**: Writes an analog value (PWM wave) to a specified pin.




```
int value = analogRead(pin);

analogWrite(pin, value);
```

Example:



Common Functions Used in Arduino Programming

delay():

- **Purpose**: Pauses the program for a specified number of milliseconds.

millis():

- **Purpose**: Returns the number of milliseconds since the Arduino board began running the current program.

```
delay(milliseconds);

unsigned long currentTime = millis();
```

Common Functions Used in Arduino Programming

Serial.begin():

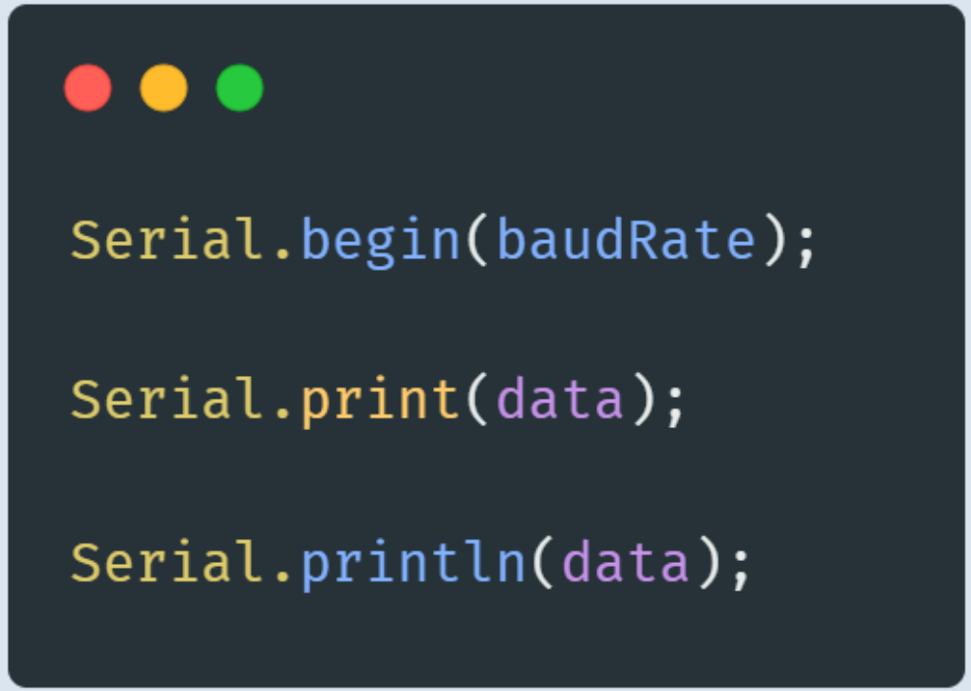
- **Purpose**: Sets the data rate in bits per second (baud) for serial data transmission.

Serial.print():

- **Purpose**: Prints data to the serial port as human-readable ASCII text.

Serial.println():

- **Purpose**: Prints data to the serial port as human-readable ASCII text, followed by a carriage return character.



Interrupts

Definition

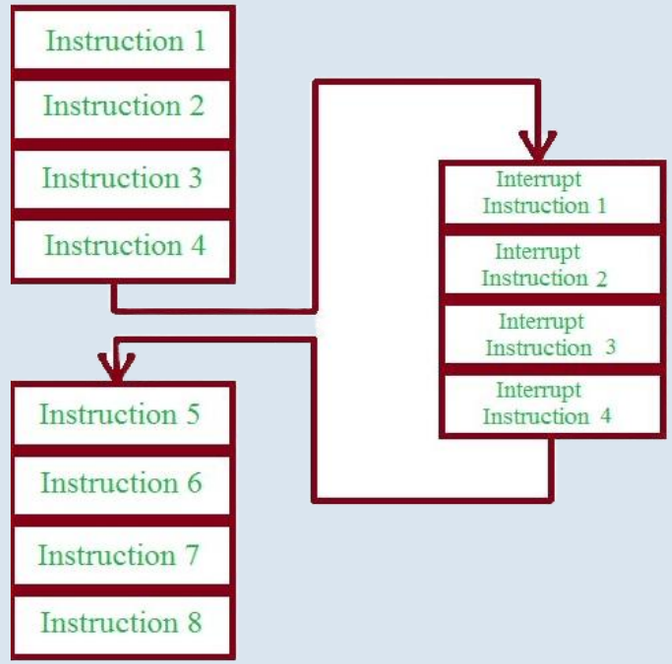
- Interrupts are signals that temporarily halt the main program execution to immediately run a special function called an Interrupt Service Routine (ISR).

Purpose

- To handle time-critical tasks, respond to external events, or process real-time signals without delay.

Benefits

- Allows for efficient handling of tasks without continuously checking for events within the main loop.



Using Interrupts in Arduino

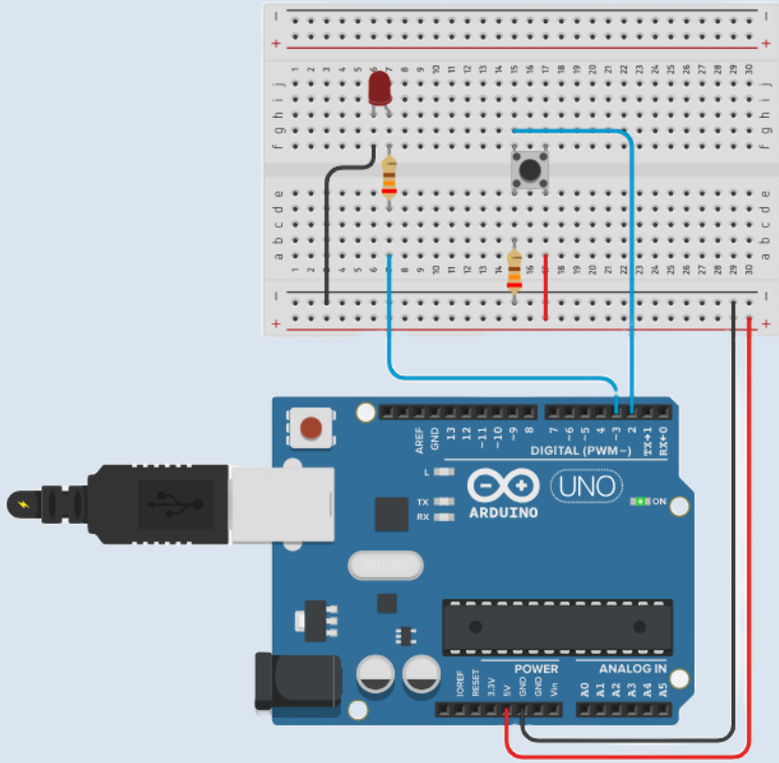
Attaching an Interrupt:

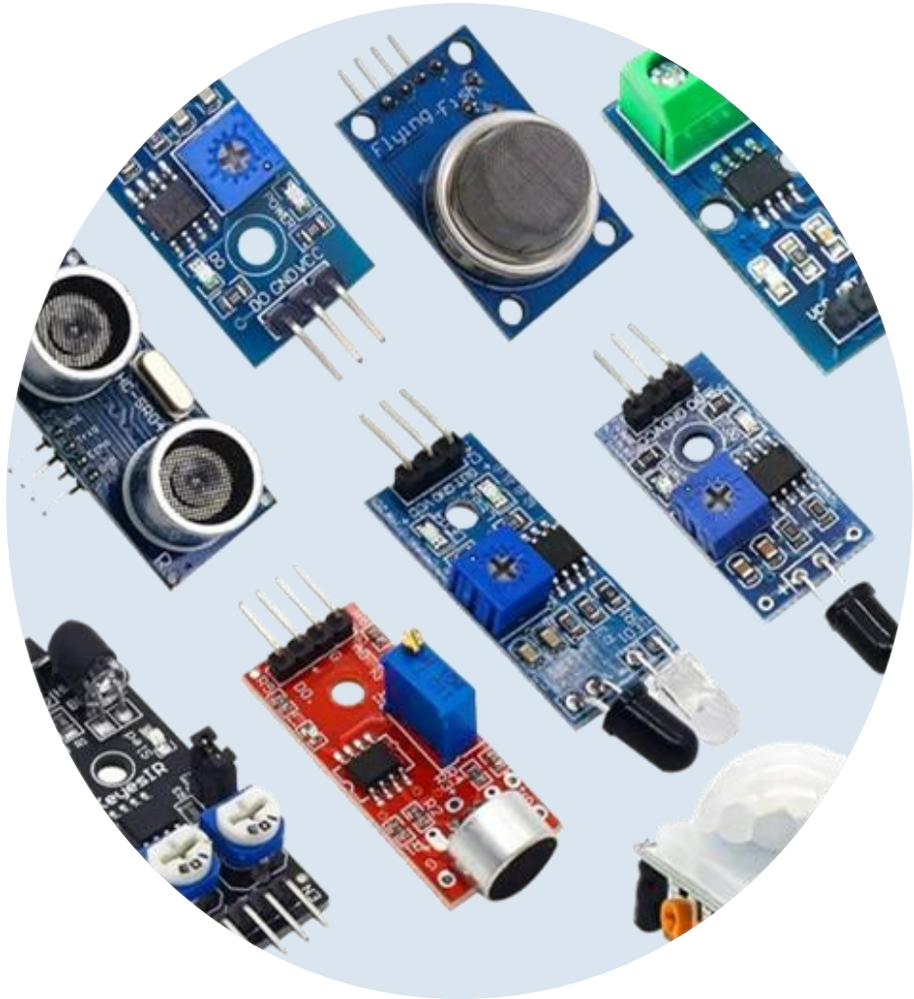
- Use the attachInterrupt() function to specify which pin and condition will trigger the interrupt, and which ISR to call.

```
attachInterrupt(digitalPinToInterrupt(pin), ISR, mode);
```

- Parameters:
  - pin: The pin number where the interrupt is attached.
  - ISR: The name of the function to call when the interrupt occurs.
  - mode: The condition that triggers the interrupt (LOW, CHANGE, RISING, FALLING).

Example:





Sensors

Ultrasonic Sensor

Introduction:

- **Definition:** Ultrasonic sensors use sound waves to measure the distance between the sensor and an object.
- **Common Model:** HC-SR04.

Working Principle:

- **Sound Waves:** Sends out an ultrasonic wave and measures the time it takes for the echo to return.
- **Distance Calculation:** Uses the speed of sound to calculate distance based on the time it took for the echo to return.

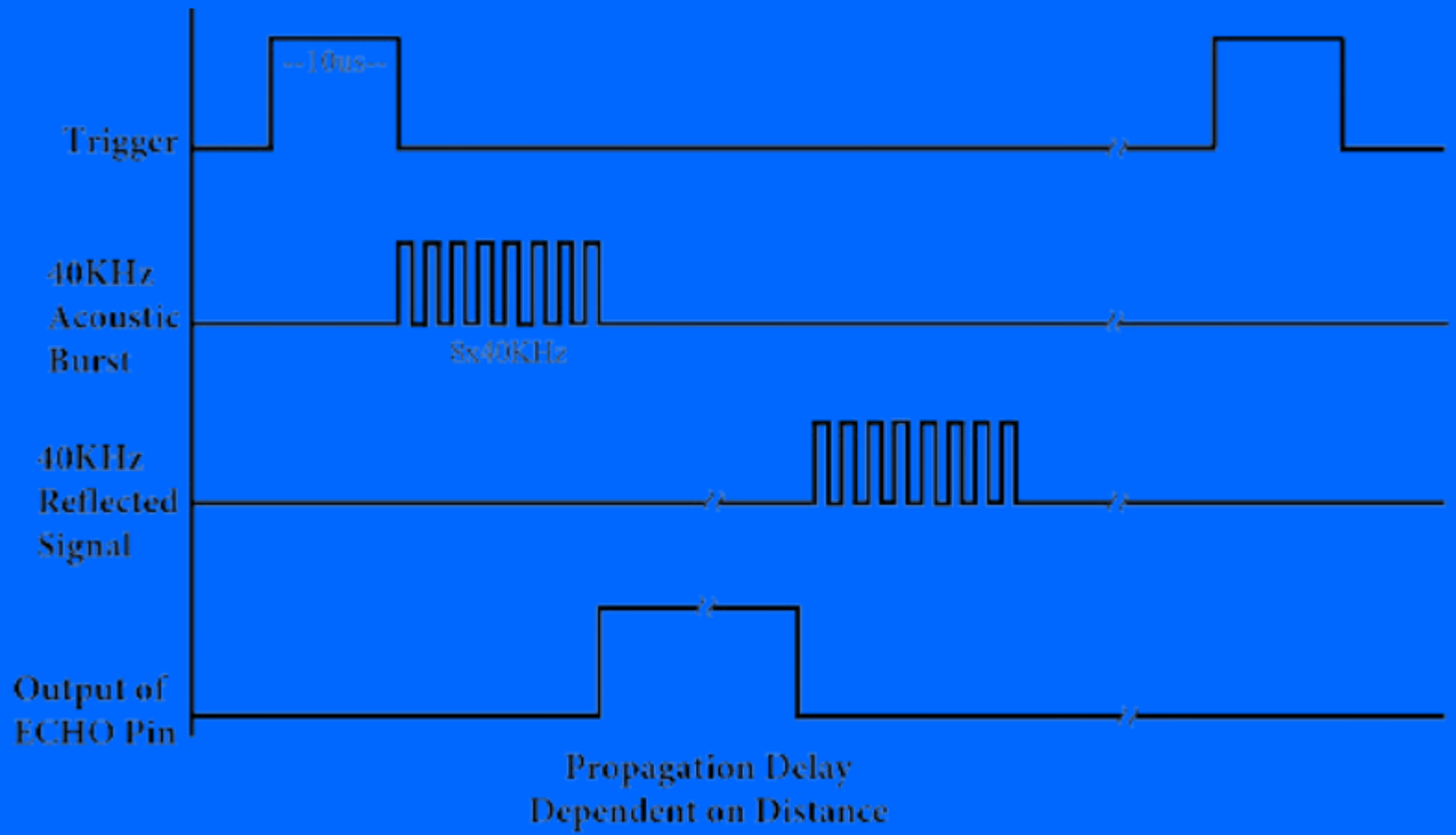
Pin Configuration

VCC: +5V Power Supply

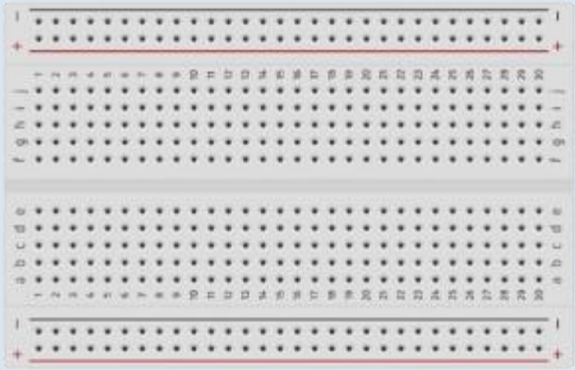
GND: Ground

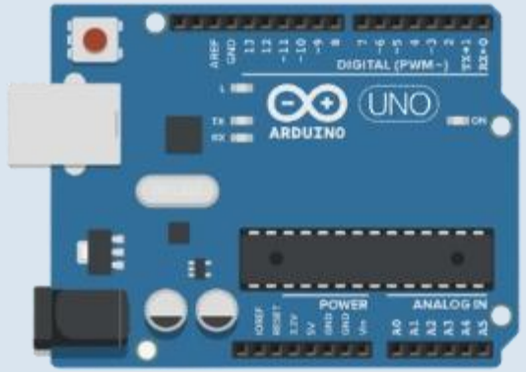
Trig: Trigger Pin

Echo: Echo Pin



Example:





IR Sensor

Introduction:

- **Definition:** Infrared (IR) sensors use infrared light to detect objects or measure the distance between the sensor and an object.
- **Common Model:** TCRT5000.

Working Principle:

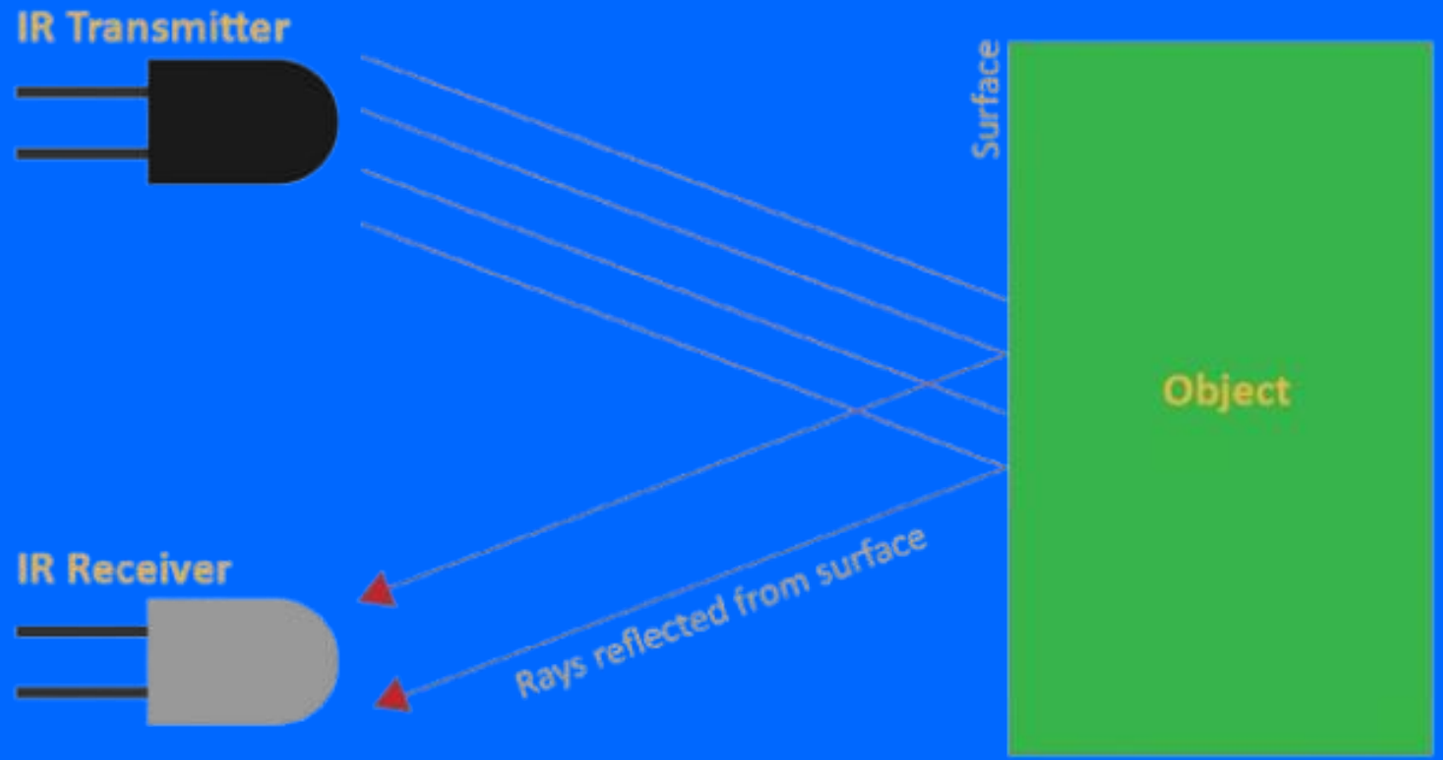
- **Infrared Light:** Emits an infrared light beam and detects the reflection from an object.
- **Distance Calculation:** Measures the intensity of the reflected light to determine the presence or distance of an object.

Pin Configuration

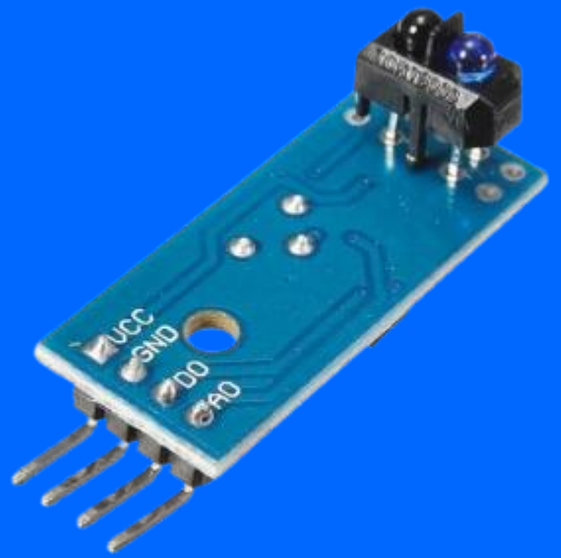
VCC: +5V Power Supply

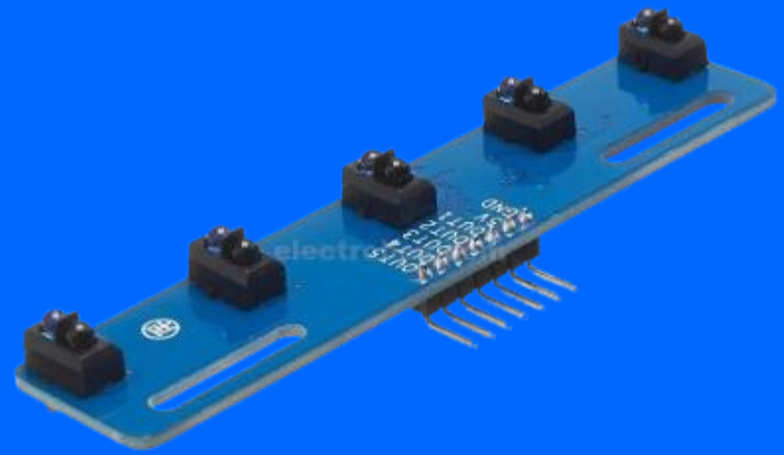
GND: Ground

OUT: Output pin

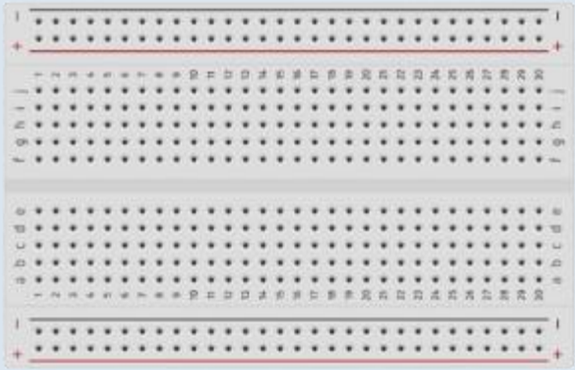


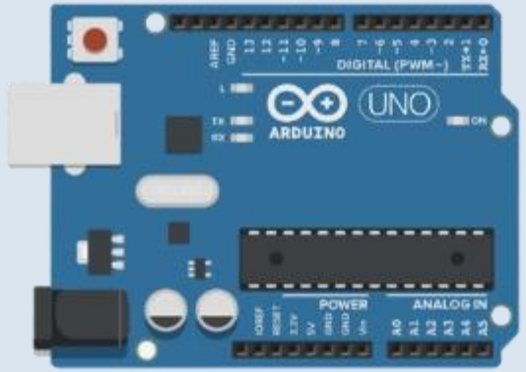
Other models for the IR sensor





Example:





LIDAR Sensor

Introduction:

- **Definition:** The VL6180X is a laser range finder (micro LIDAR) that uses time-of-flight (ToF) technology to measure the distance between the sensor and an object with high precision.
- **Common Model:** VL6180X.

Working Principle:

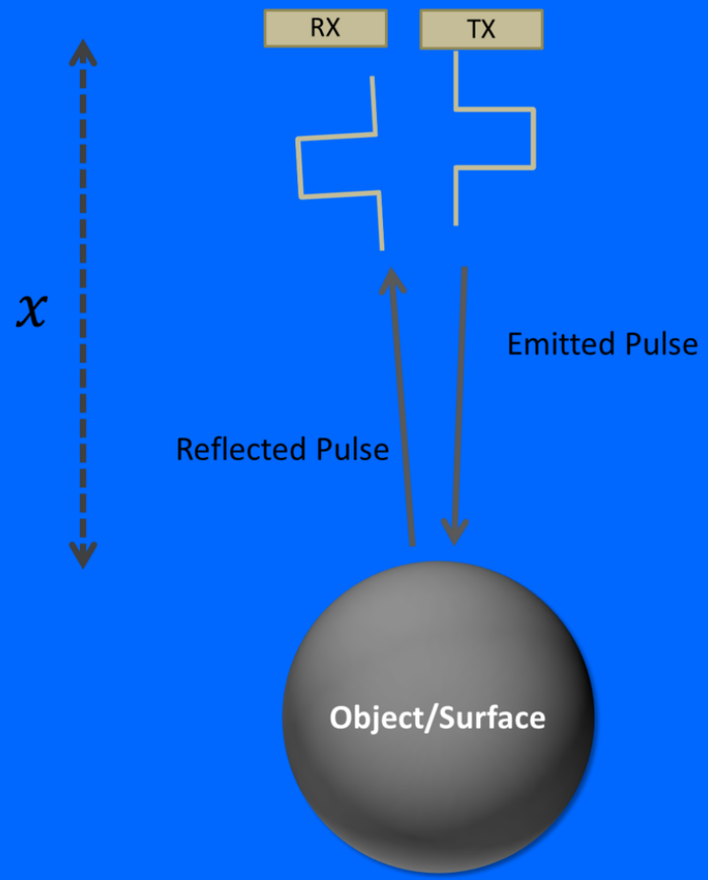
- **Laser Emission:** Emits a laser pulse toward the target object.
- **Time-of-Flight Measurement:** Measures the time it takes for the laser pulse to reflect off the object and return to the sensor.
- **Distance Calculation:** Uses the speed of light to calculate the distance based on the time-of-flight of the laser pulse.

Pin Configuration

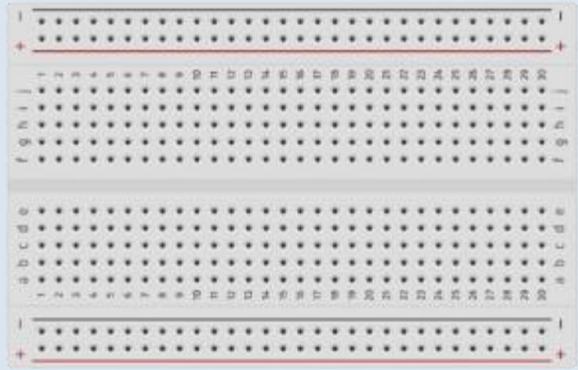
VCC: +5V Power Supply

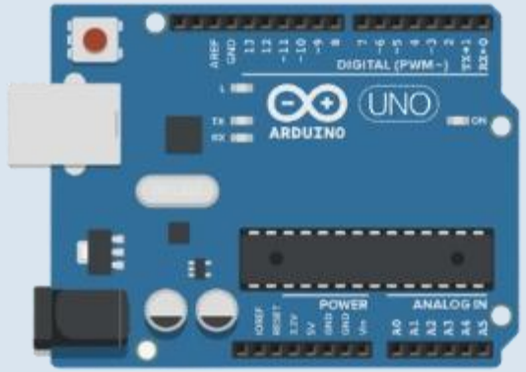
GND: Ground

I2C PIN: Communication with the sensor

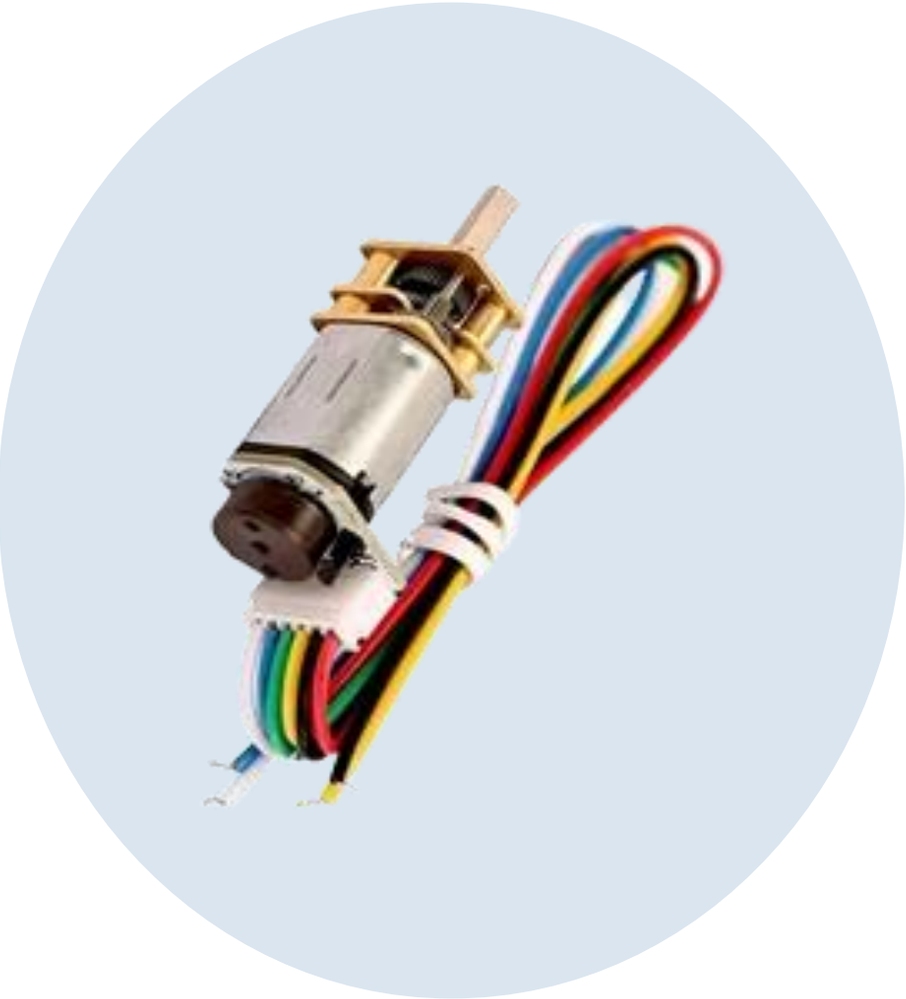


Example:





Motor



Wheels

Motor with Encoder:

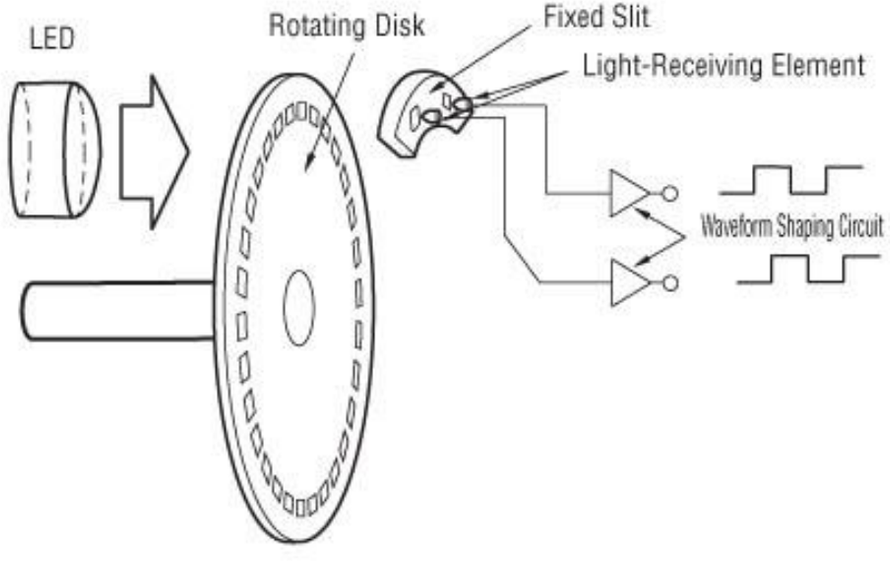
Has a sensor to provide position, speed, and direction feedback for precise control.

Motor without Encoder:

Lacks feedback, offering simpler, cost-effective control but less accuracy.

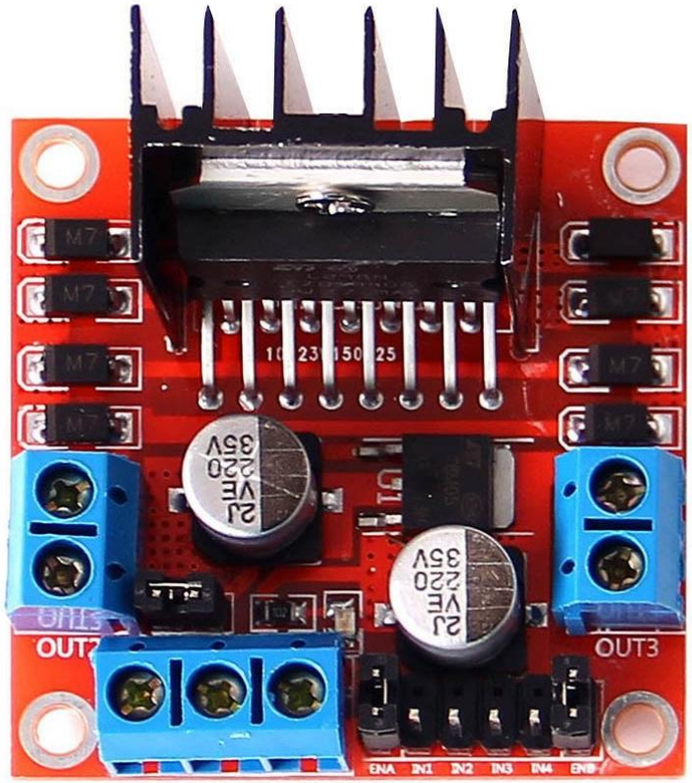
How encoder works:

Optical encoder. It uses an LED and a rotating disk. and light-receiving elements generate electrical signals. These signals represent the position, speed, and direction of the motor.



H-Bridge (Motor Driver L298N)

L298N H-Bridge is a motor driver module that allows control of two DC motors. It supports forward/reverse rotation, speed control via PWM.



How to connect:

Method 1:

Direction Control:

Two input pins (IN1, IN2) for each motor determine the motor's direction.

IN1= High , IN2 = Low → Motor rotates forward.

IN1= Low , IN2 = High → Motor rotates backward.

Speed Control:

Speed is adjusted using Pulse Width Modulation (PWM) applied to the Enable pin (EN).

Higher duty cycle → Faster speed.

Lower duty cycle → Slower speed

Method 2:

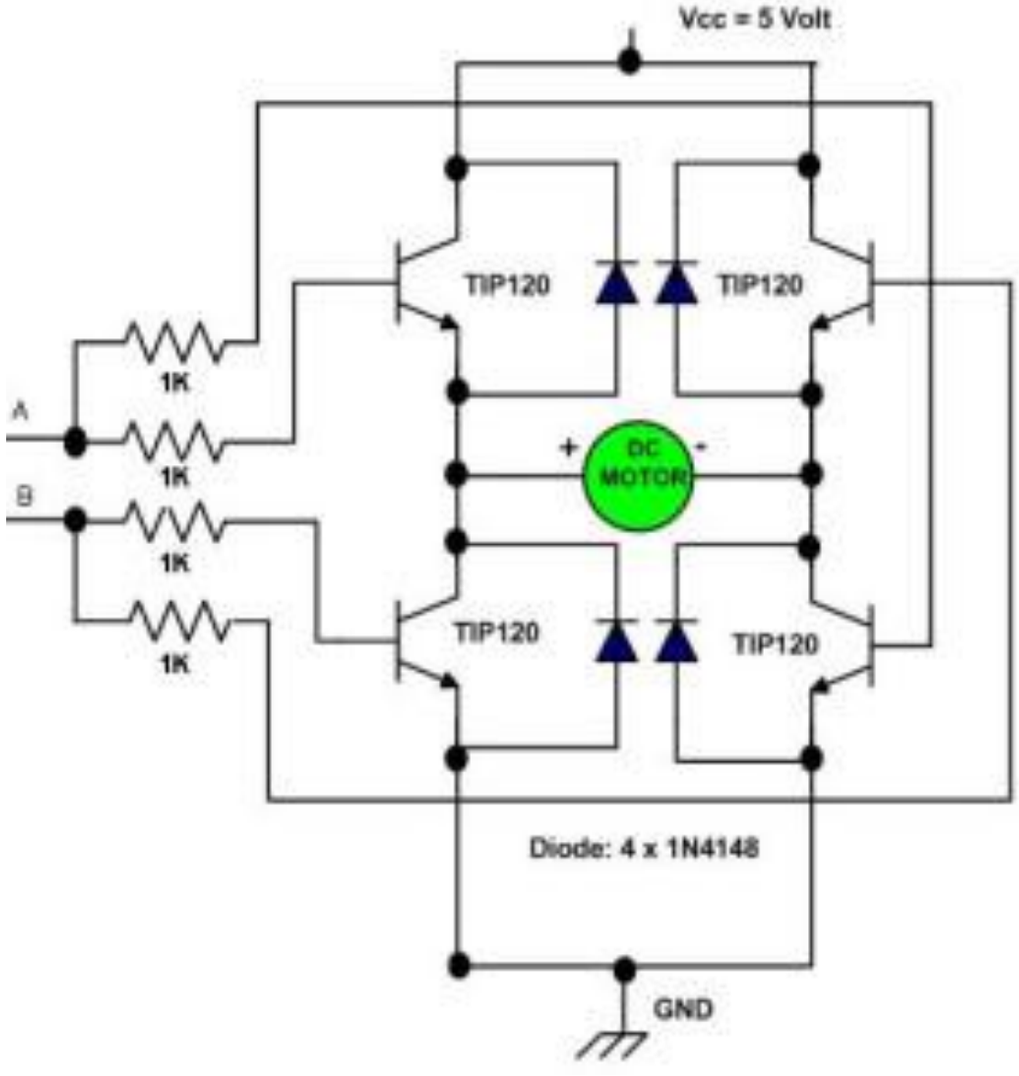
Direction and Speed Control:

Connect EN to 5 volt use jumper then

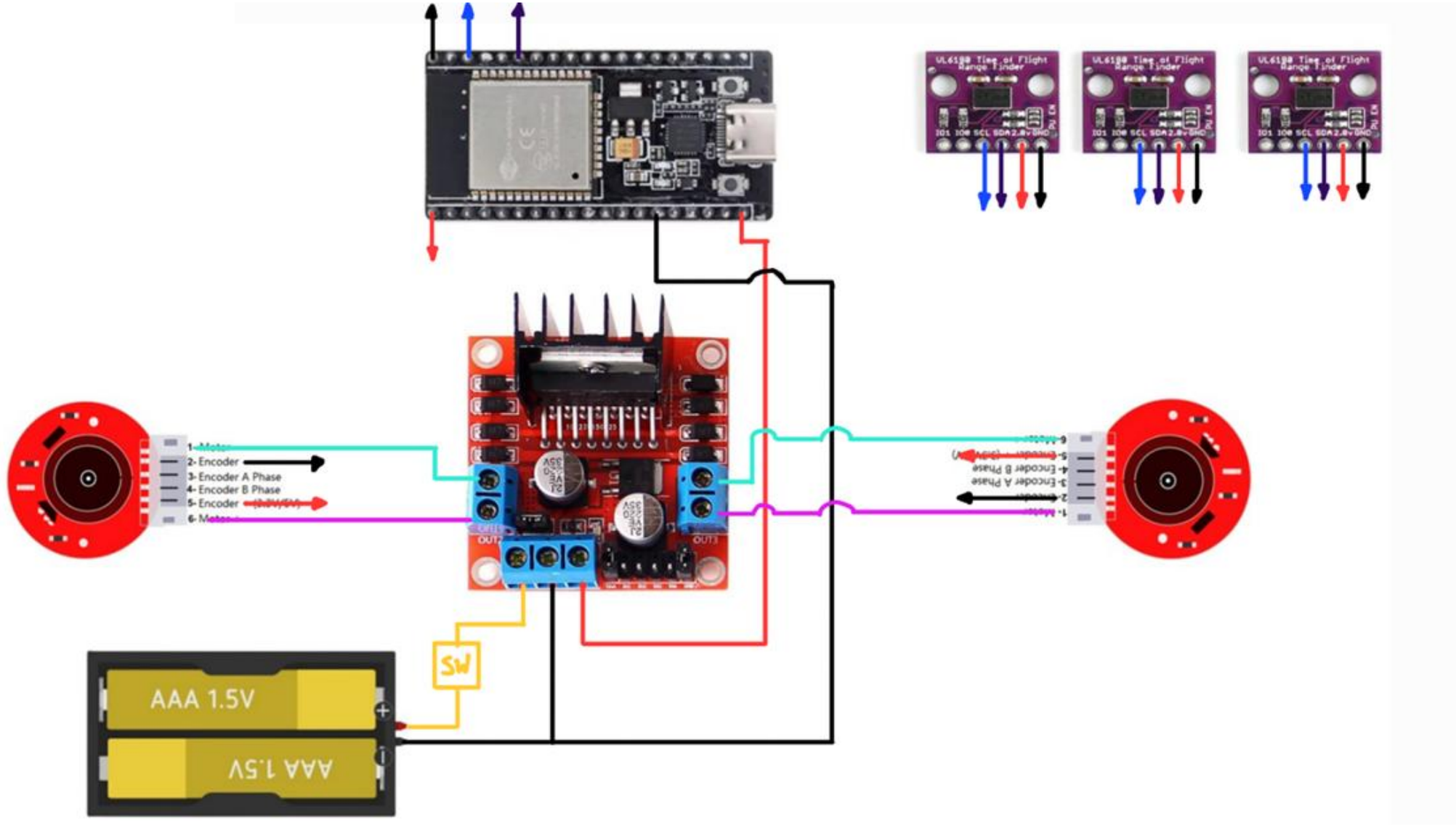
IN1 = PWM, IN2 = LOW → Forward speed controlled by IN1's PWM.

IN1 = LOW, IN2 = PWM → Reverse speed controlled by IN2's PWM.

How H-Bridge works:



How H-Bridge works:

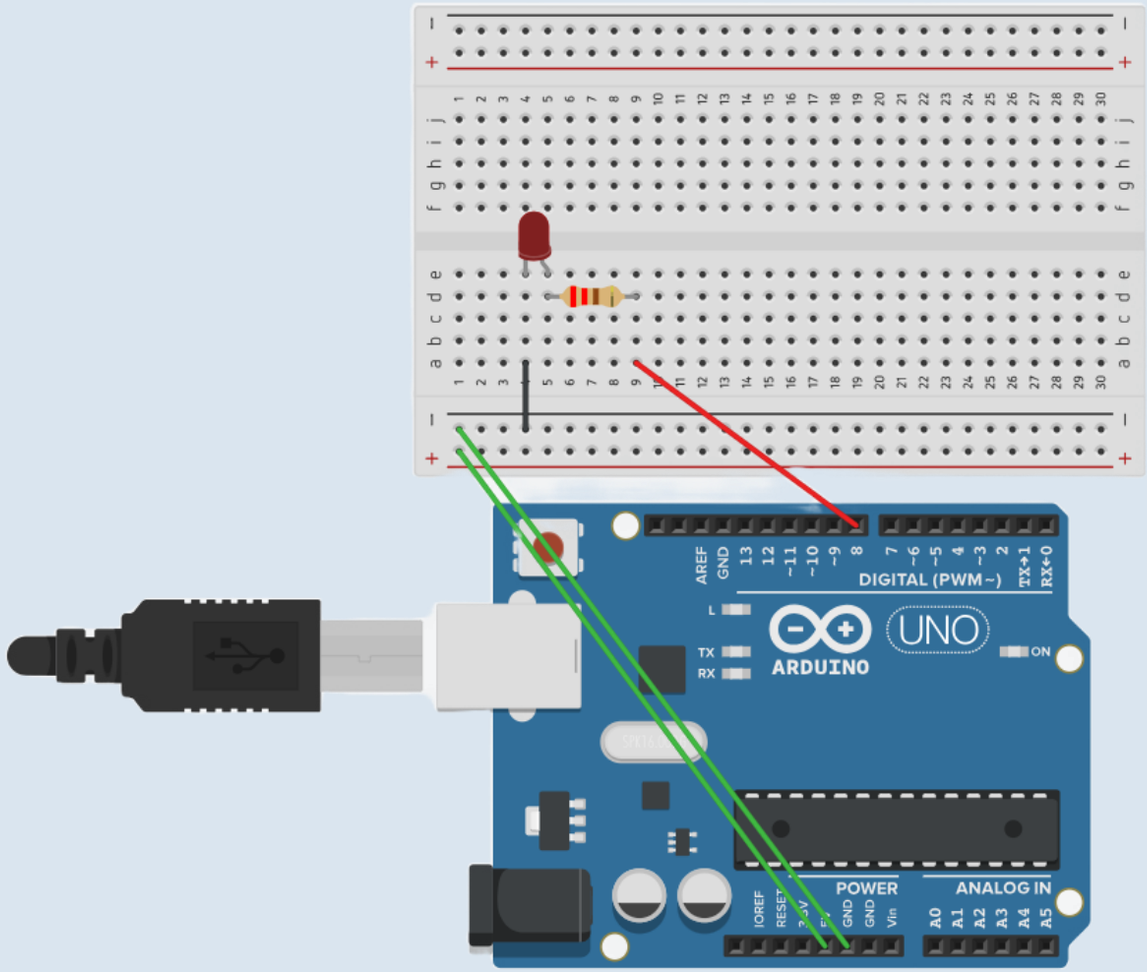


Examples

Example 1 => Blinking LED

Blinking LED using Delay function:

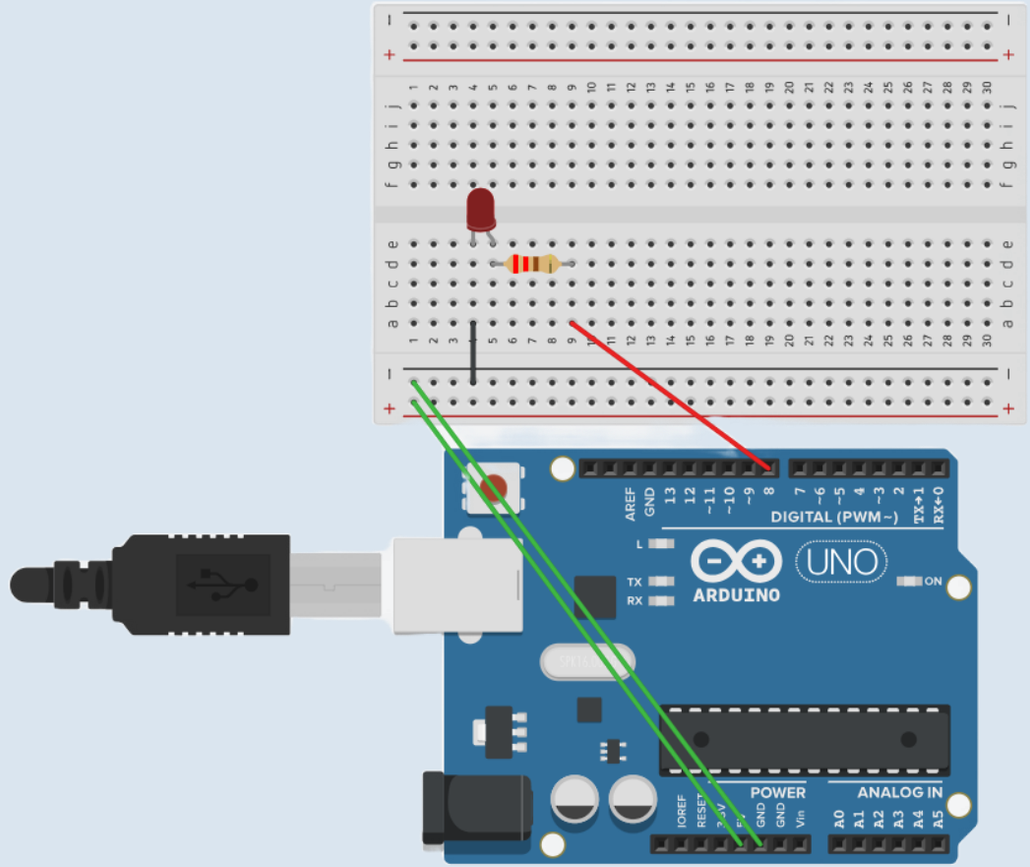
```
int ledPin=8;

void setup(){
    pinMode(ledPin,OUTPUT);
}

void loop(){
    digitalWrite(ledPin,HIGH);
    delay(1000);
    digitalWrite(ledPin,LOW);
    delay(1000);
}
```



Example 2 => Blinking LED

Blinking LED using millis function:

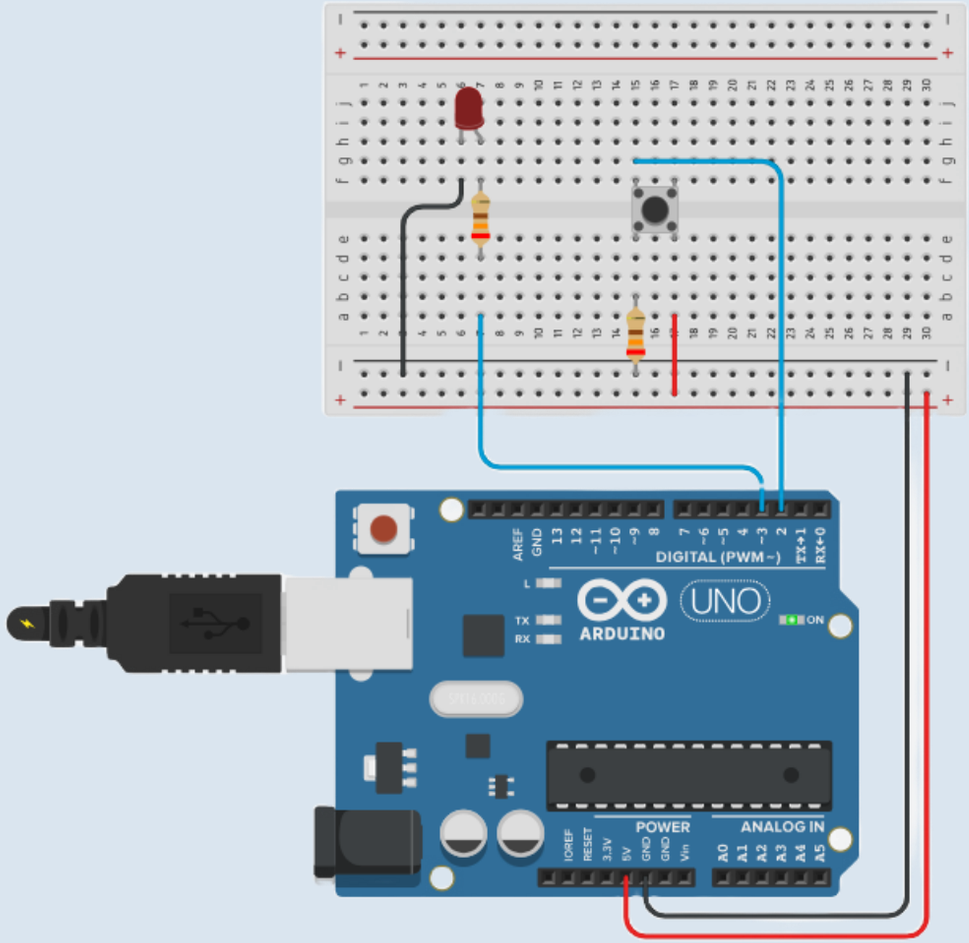
```
int ledPin = 8;
unsigned long previousMillis = 0;
const long interval = 1000;

void setup() {
    pinMode(ledPin, OUTPUT);
}

void loop() {
    unsigned long currentMillis = millis();

    if (currentMillis - previousMillis ⩾ interval) {
        previousMillis = currentMillis;

        if (digitalRead(ledPin) == LOW)
            digitalWrite(ledPin, HIGH);
        else
            digitalWrite(ledPin, LOW);
    }
}
```



Example 3 => Toggle LED

Toggle LED without interrupts:

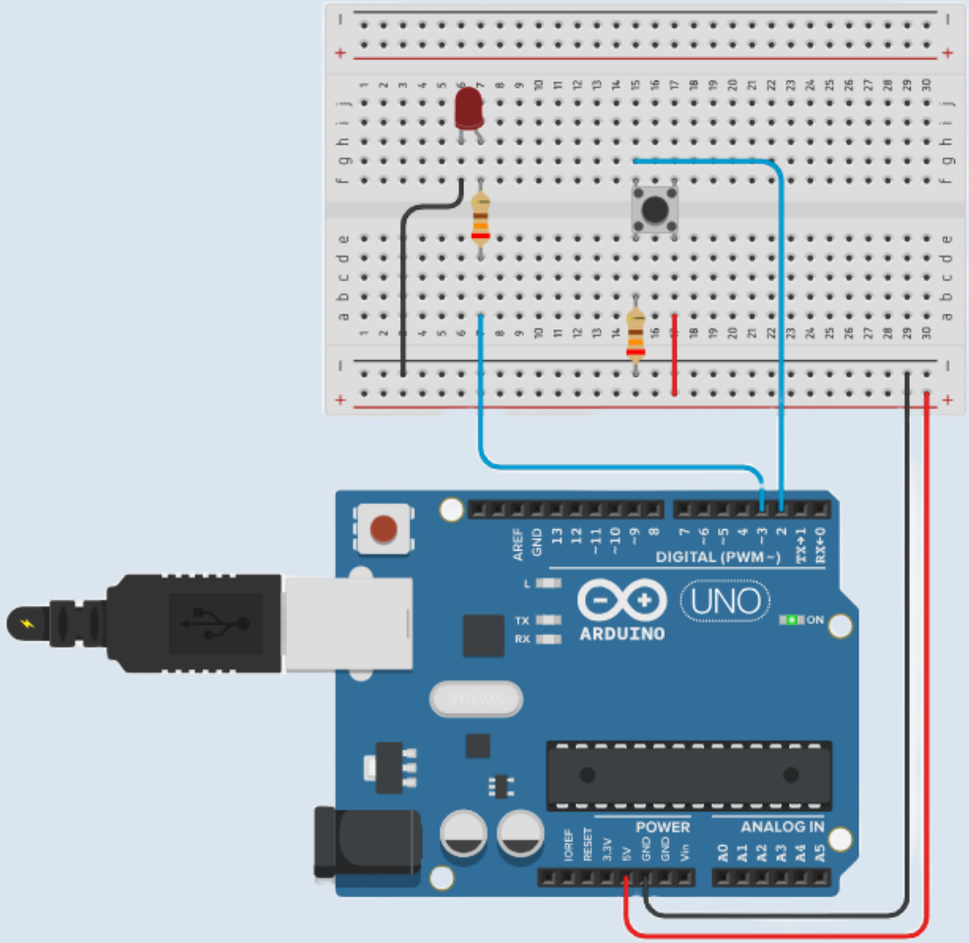
```arduino
const int Switch = 2, LED = 3;
int state = 0, LEDstate=0;

void setup(){
  pinMode(Switch, INPUT);
  pinMode(LED, OUTPUT);
}

void loop(){
  if (state == 0 && digitalRead(Switch) == HIGH) {
    state = 1;
    LEDstate=!LEDstate;
  }
  if (state == 1 && digitalRead(Switch) == LOW) {
    state = 0;
  }
  digitalWrite(LED, LEDstate);
}
```



Example 4 => Toggle LED

Toggle LED with interrupts:

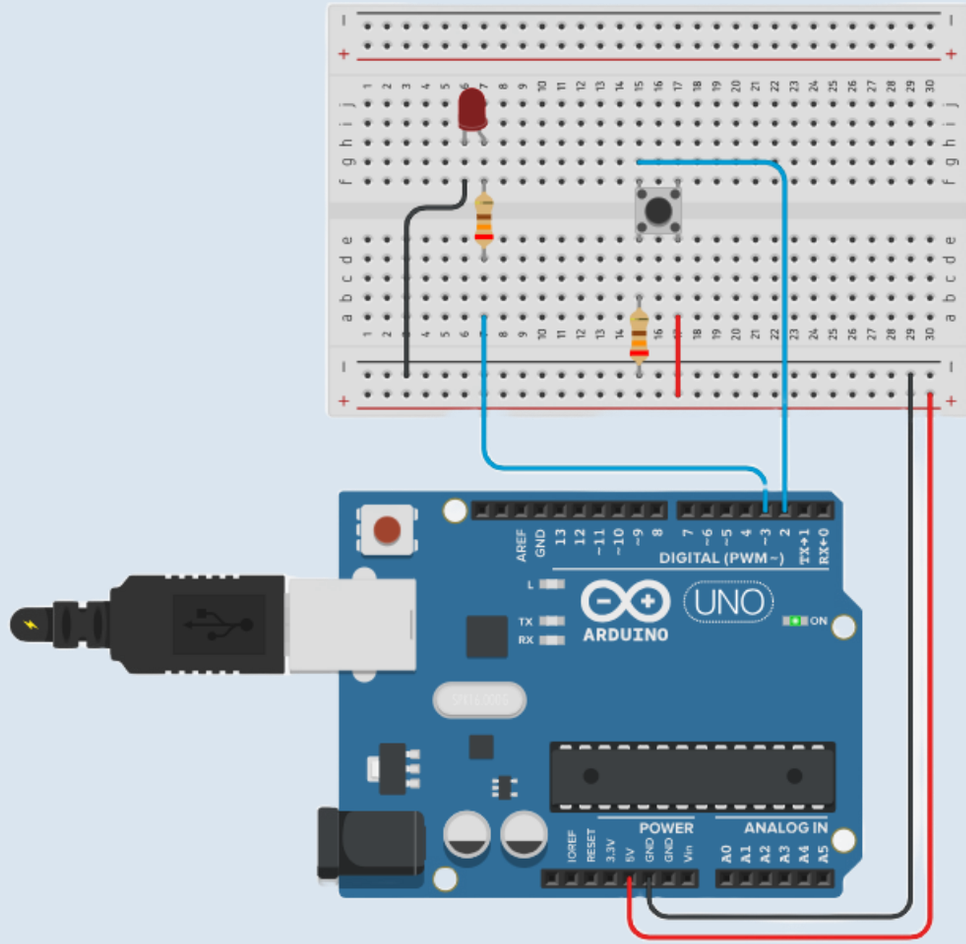
```
const int buttonPin = 2;
const int ledPin = 3;
volatile int LEDstate = LOW;

void setup() {
    pinMode(buttonPin, INPUT);
    pinMode(ledPin, OUTPUT);
    attachInterrupt(digitalPinToInterrupt(buttonPin),
                    toggleLED, RISING);
}

void loop() {
}

void toggleLED() {
    LEDstate = !LEDstate;
    digitalWrite(ledPin, LEDstate);
}
```



Example 5 => Toggle LED

Toggle LED with interrupts and avoid bouncing effect:

```
const int buttonPin = 2;
const int ledPin = 3;
volatile int LEDstate = LOW;
volatile unsigned long lastDebounceTime = 0;
const unsigned long debounceDelay = 50;

void setup() {
    pinMode(buttonPin, INPUT);
    pinMode(ledPin, OUTPUT);
    attachInterrupt(digitalPinToInterrupt(buttonPin),
                    toggleLED, RISING);
}

void loop() {
}

void toggleLED() {
    unsigned long currentTime = millis();
    if (currentTime - lastDebounceTime
        > debounceDelay) {
        LEDstate = !LEDstate;
        lastDebounceTime = currentTime;
        digitalWrite(ledPin, LEDstate);
    }
}
```



Example 6 => Controlling LED

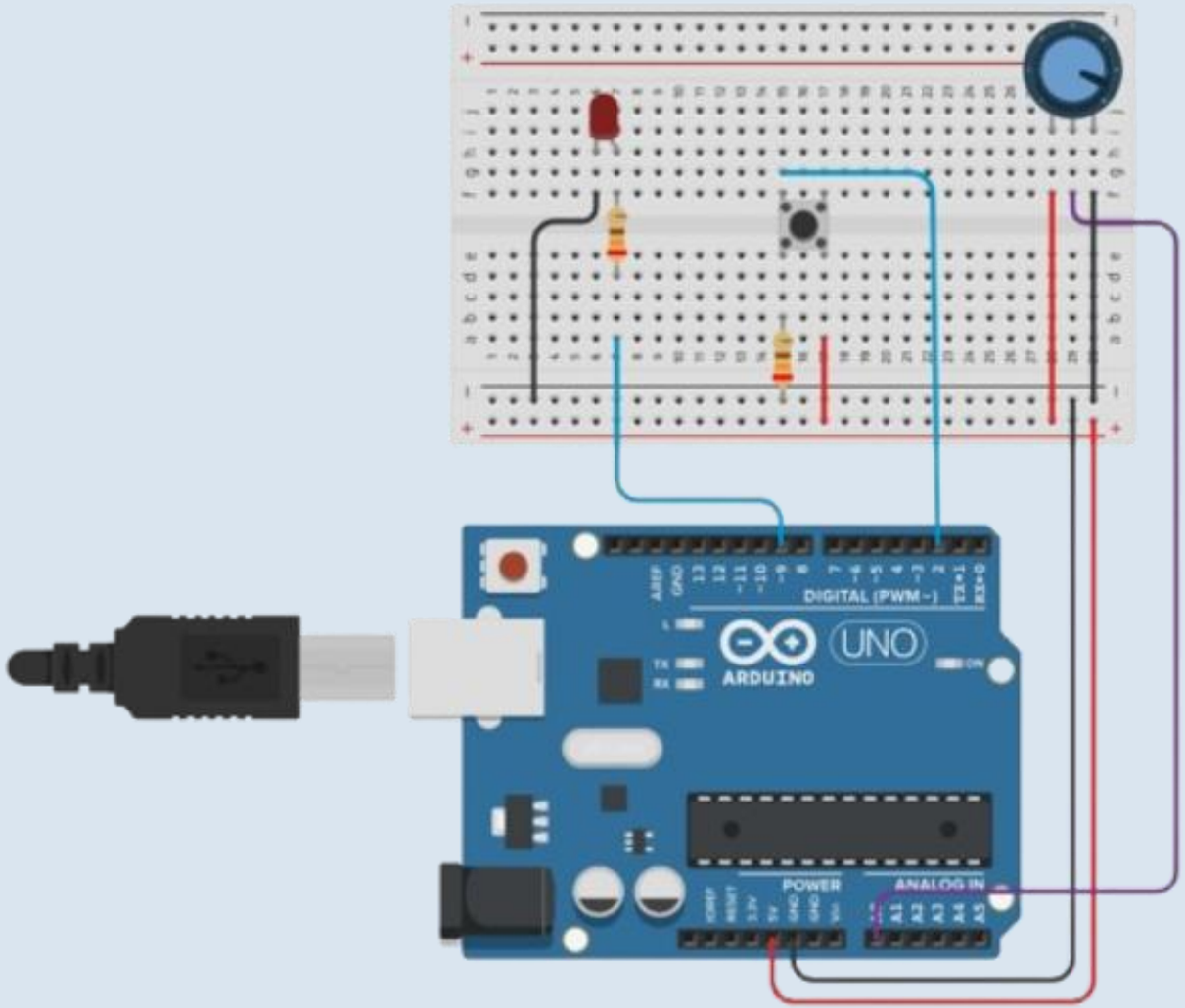
Creating an interactive system using an Arduino that involves the following components:

- Potentiometer
- Button
- LED

Requirements:

- The potentiometer should control the brightness of the LED.
- Button should toggle the LED on and off.
- Use interrupts to handle the button presses efficiently.

Example 6 => Controlling LED



Example 6 => Controlling LED

```
const int potPin = A0;
const int ledPin = 9;
const int button1Pin = 2;

volatile bool ledState = false;
int potValue = 0;
int brightness = 0;

void setup() {
  pinMode(ledPin, OUTPUT);
  pinMode(button1Pin, INPUT);

  attachInterrupt(digitalPinToInterrupt(button1Pin), toggleLED, RISING);
}

void loop() {

  potValue = analogRead(potPin);
  brightness = map(potValue, 0, 1023, 0, 255);

  if (ledState) {
    analogWrite(ledPin, brightness);
  } else {
    analogWrite(ledPin, 0);
  }

  delay(10); // Small delay to avoid rapid changes
}

void toggleLED() {
  ledState = !ledState;
}
```

Example 7 => Controlling Array of LEDs

Unsolved example

You need to create an Arduino system that controls four LEDs based on the value of a potentiometer.

Requirements:Use a potentiometer to determine how many LEDs should be turned on.

The system should work as follows:

- If the potentiometer value is between 0 and 255, turn on 1 LED.
- If the potentiometer value is between 256 and 511, turn on 2 LEDs.
- If the potentiometer value is between 512 and 767, turn on 3 LEDs.
- If the potentiometer value is between 768 and 1023, turn on all 4 LEDs.

Example 8 => LED Reaction Game

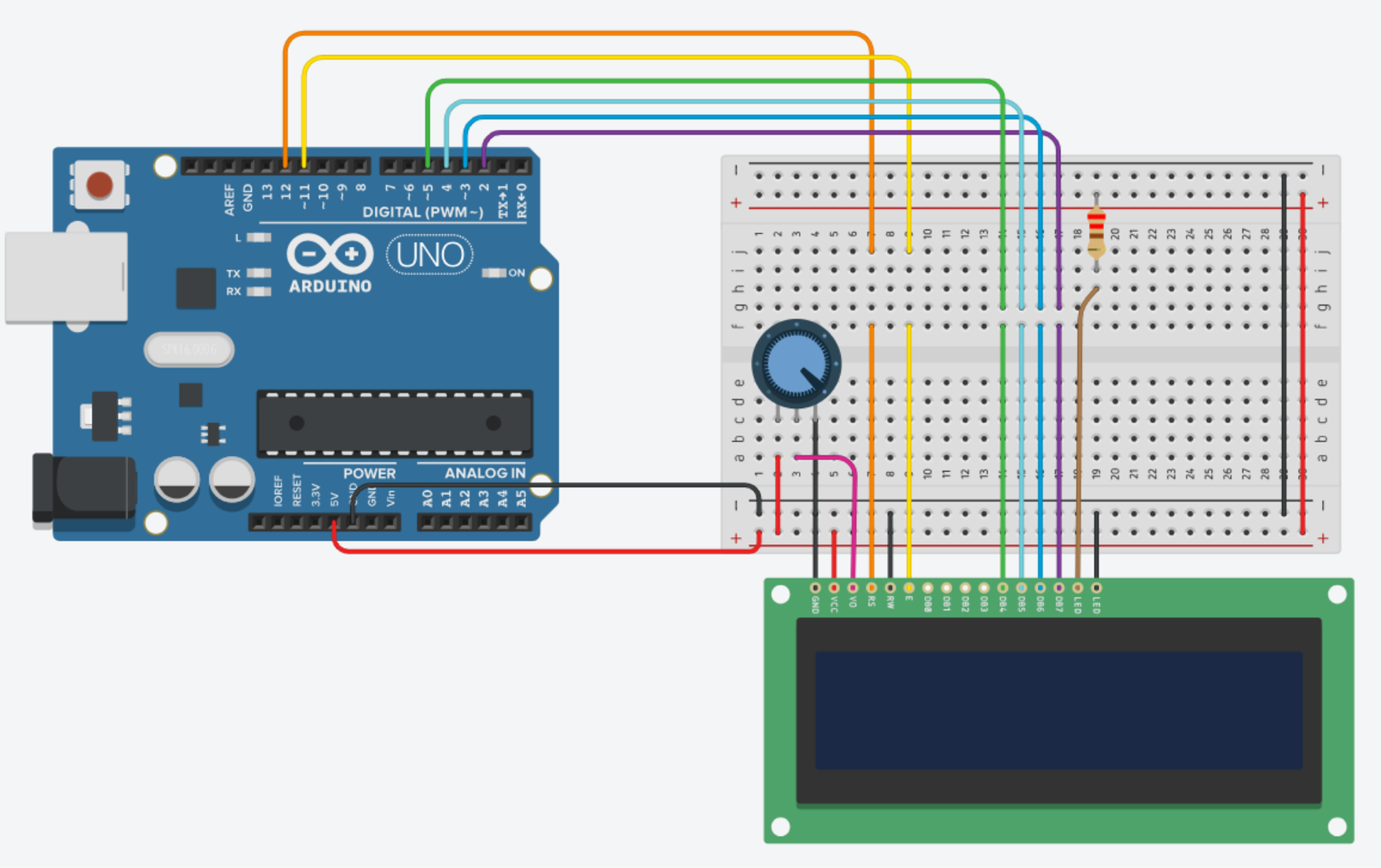
Unsolved example

Design an Arduino-based reaction game that uses LEDs, a potentiometer, and a button. The goal of the game is to test the player's reaction time.

Requirements:

- Use a potentiometer to set the difficulty level of the game.
- An LED should light up randomly after a delay.
- The player must press a button as quickly as possible when the LED lights up.
- The system should display the player's reaction time using LEDs.
- The game should reset automatically after displaying the reaction time.

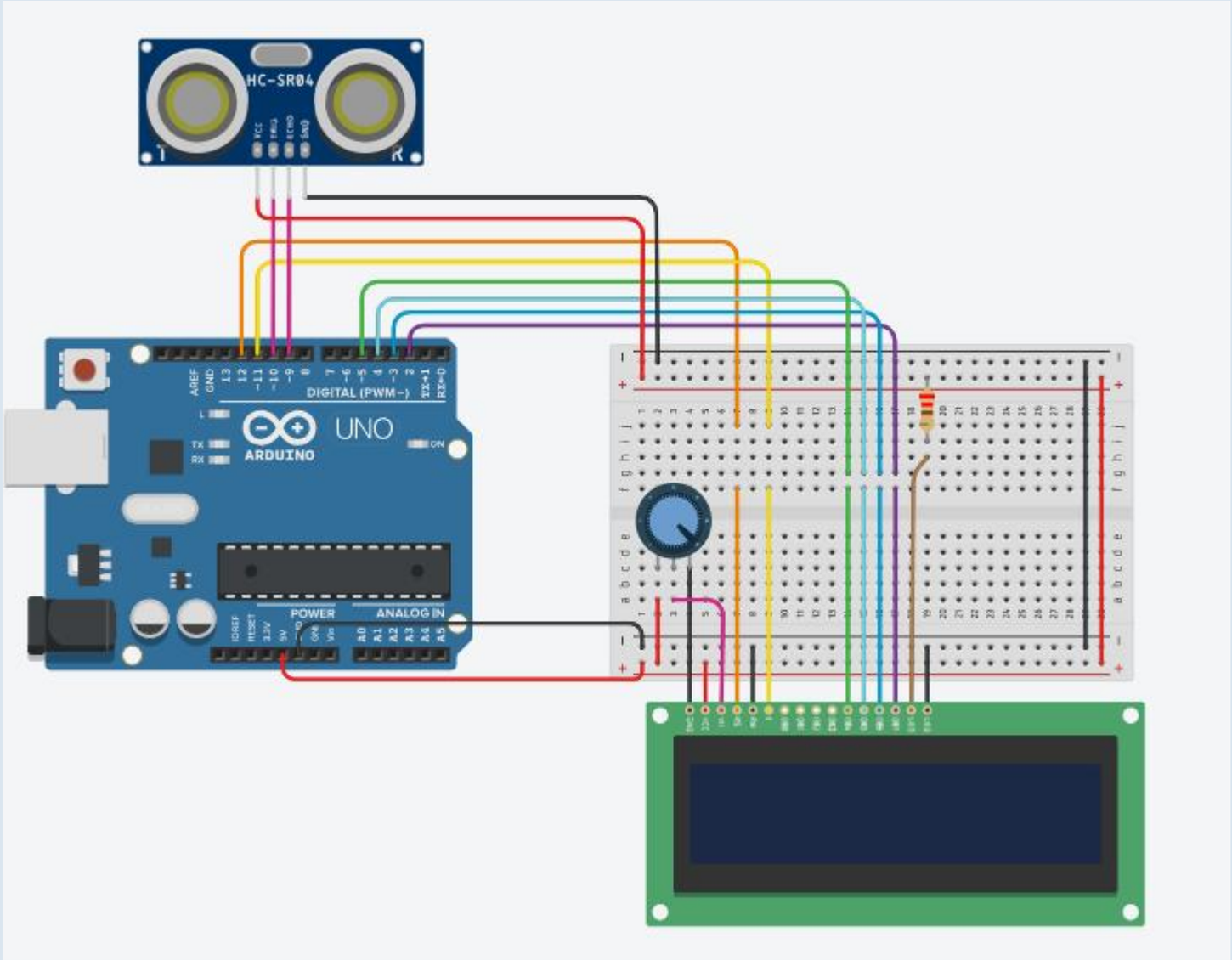
Example 9 => Print Your Name



Example 9 => Print Your Name

```
#include <LiquidCrystal.h>

// LiquidCrystal(rs, enable, d4, d5, d6, d7)
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);

void setup()
{
  lcd.begin(16, 2);

  lcd.setCursor(0, 0);
  lcd.print("Qossay Abu Rida");
}

void loop(){
}
```

Example 10 => Distance Measurement

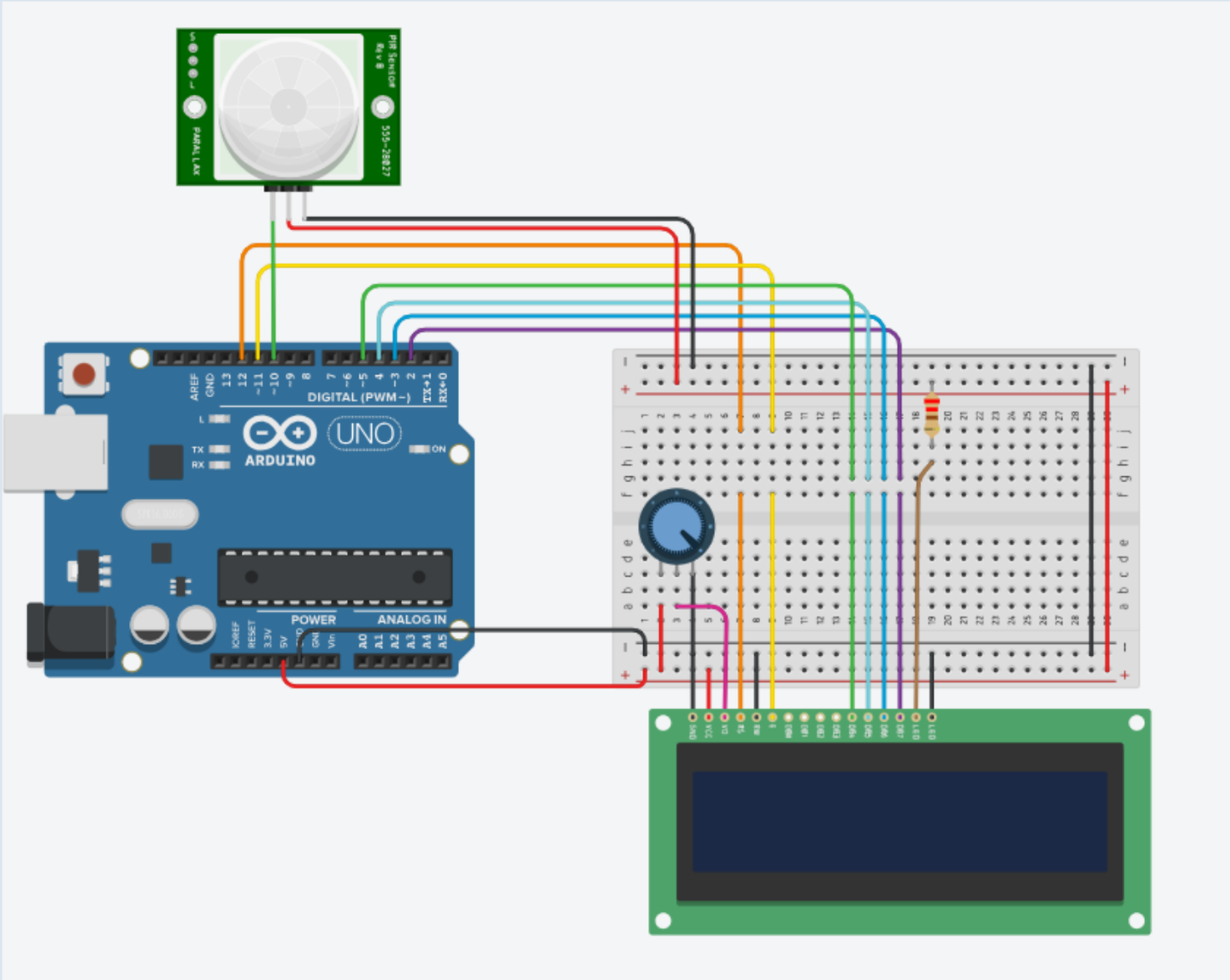


Example 10 => Distance Measurement

```
#include <LiquidCrystal.h>

LiquidCrystal lcd_1(12, 11, 5, 4, 3, 2);
const int trigPin = 10;
const int echoPin = 9;

void setup() {
  lcd_1.begin(16, 2);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  lcd_1.print("Distance: ");
}

void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  long duration = pulseIn(echoPin, HIGH);
  float distance = duration * 0.034 / 2;

  lcd_1.setCursor(0, 1);
  lcd_1.print("                "); // Clear previous reading
  lcd_1.setCursor(0, 1);
  lcd_1.print(distance);
  lcd_1.print(" cm");

  delay(500);
}
```

The speed of sound in air is approximately 343 meters per second or 0.0343 centimeters per microsecond.

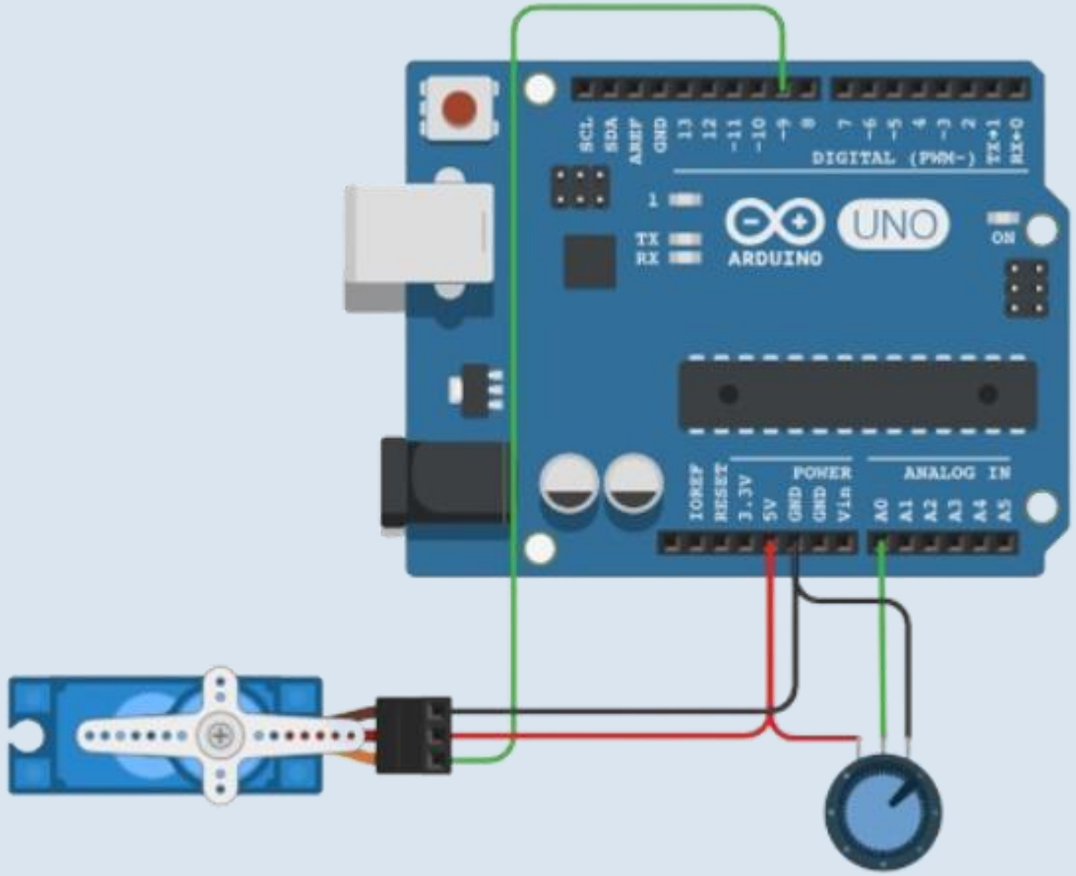
Example 11 => Motion detection



Example 11 => Motion detection

```
#include <LiquidCrystal.h>

LiquidCrystal lcd_1(12, 11, 5, 4, 3, 2);
const int pirPin = 10;

void setup() {
  lcd_1.begin(16, 2);
  pinMode(pirPin, INPUT);
  lcd_1.print("PIR Sensor:");
}

void loop() {
  int pirState = digitalRead(pirPin);

  lcd_1.setCursor(0, 1);
  if (pirState == HIGH)
    lcd_1.print("Motion detected");
  else
    lcd_1.print("No motion      ");

  delay(500);
}
```

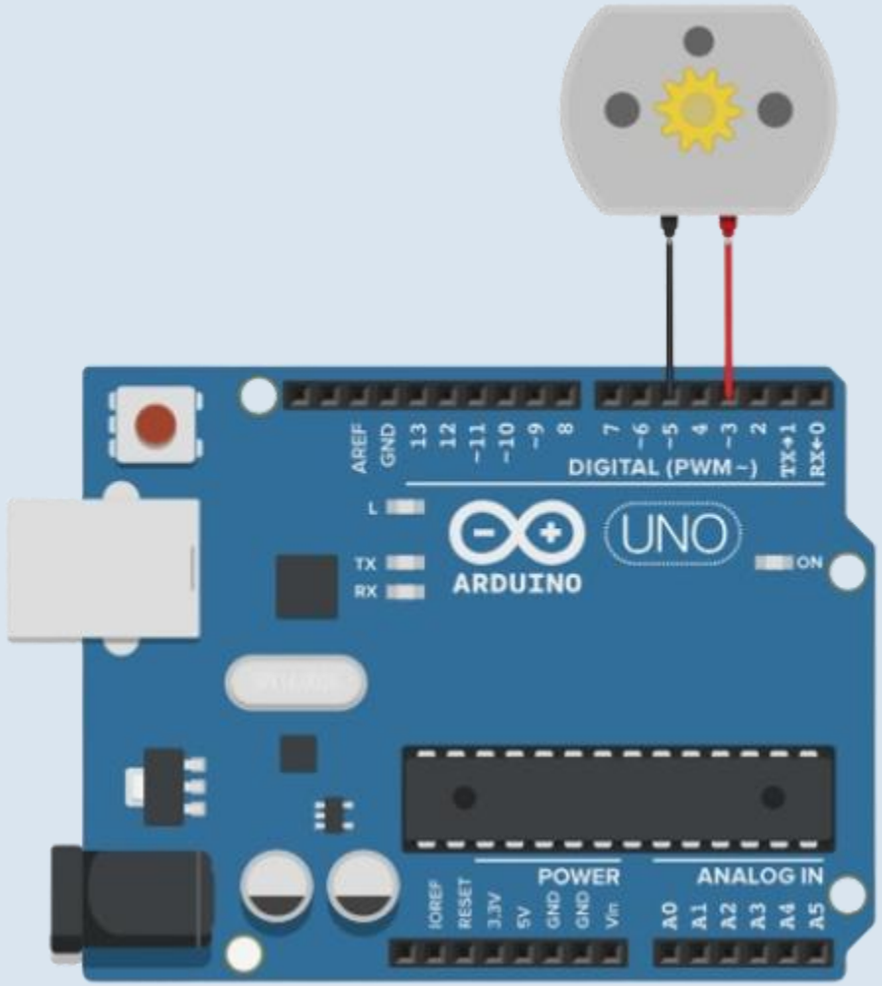
Example 12 => Servo Motors



Example 12 => Servo Motors

```
#include <Servo.h>

Servo myservo;
int value;
double angle;

void setup()
{
  Serial.begin(9600);
  myservo.attach(9);
}

void loop()
{
  value = analogRead(A0);
  angle = map(value, 0, 1023, 0, 180);
  Serial.println(angle);
  myservo.write(angle);
  delay(15);
}
```

Example 13 => DC Motors



Example 13 => DC Motors

```
int motorPin1 = 3;
int motorPin2 = 5;

void setup() {
  pinMode(motorPin1, OUTPUT);
  pinMode(motorPin2, OUTPUT);
}

void loop() {
  digitalWrite(motorPin1, HIGH);
  digitalWrite(motorPin2, LOW);
  delay(2000);
  digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, HIGH);
  delay(2000);
}
```

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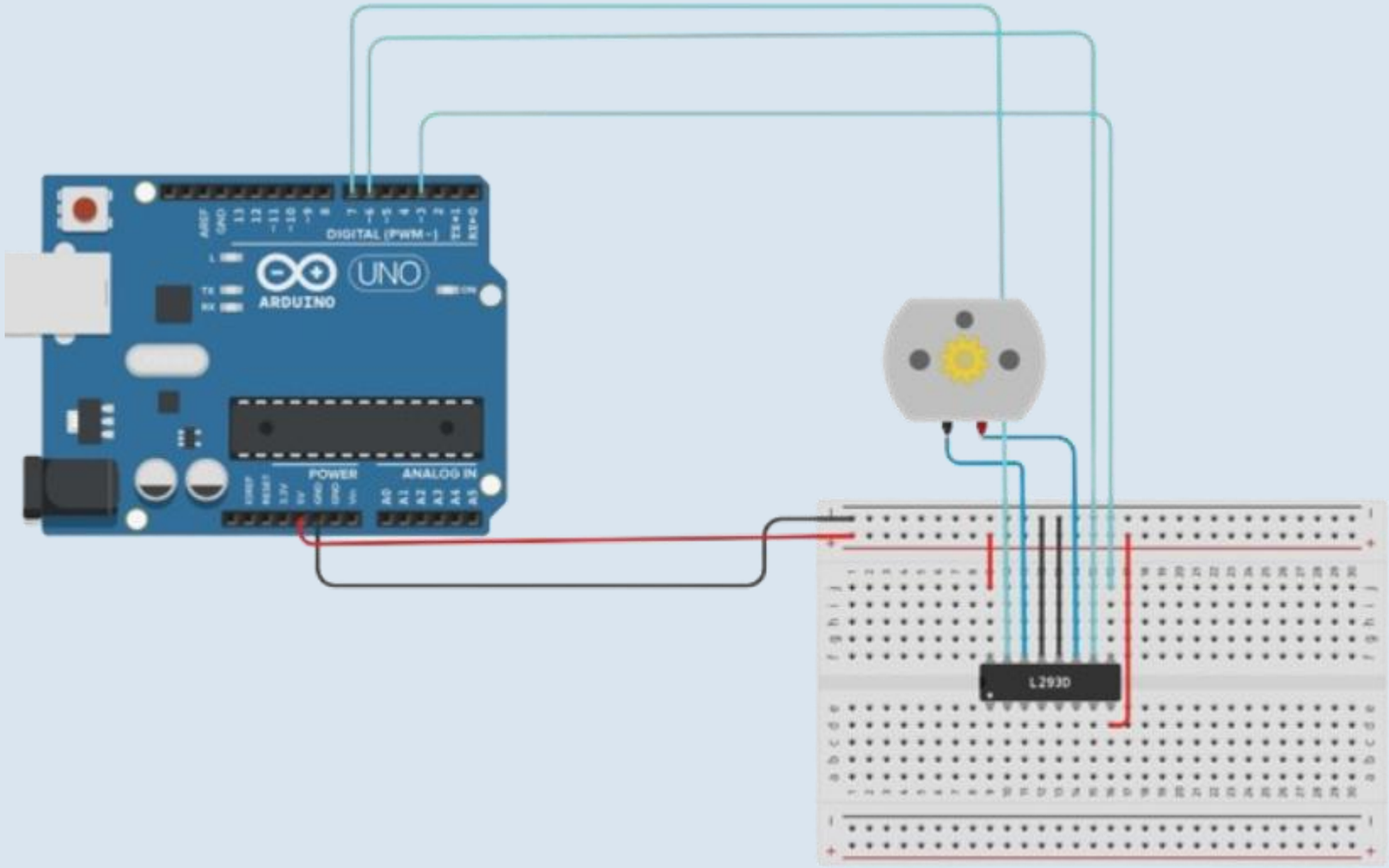
Example 14 => H-Bridge



Example 14 => H-Bridge

```
int enA = 3;
int in1 = 6;
int in2 = 7;

void setup() {
  pinMode(enA, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
}

void loop() {
  digitalWrite(in1, HIGH);
  digitalWrite(in2, LOW);
  analogWrite(enA, 255);
  delay(2000);
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH);
  delay(2000);
}
```

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