Electrics & Microcontrollers: Inputs+Outputs

Sensors, Motors, and Batteries for Makers

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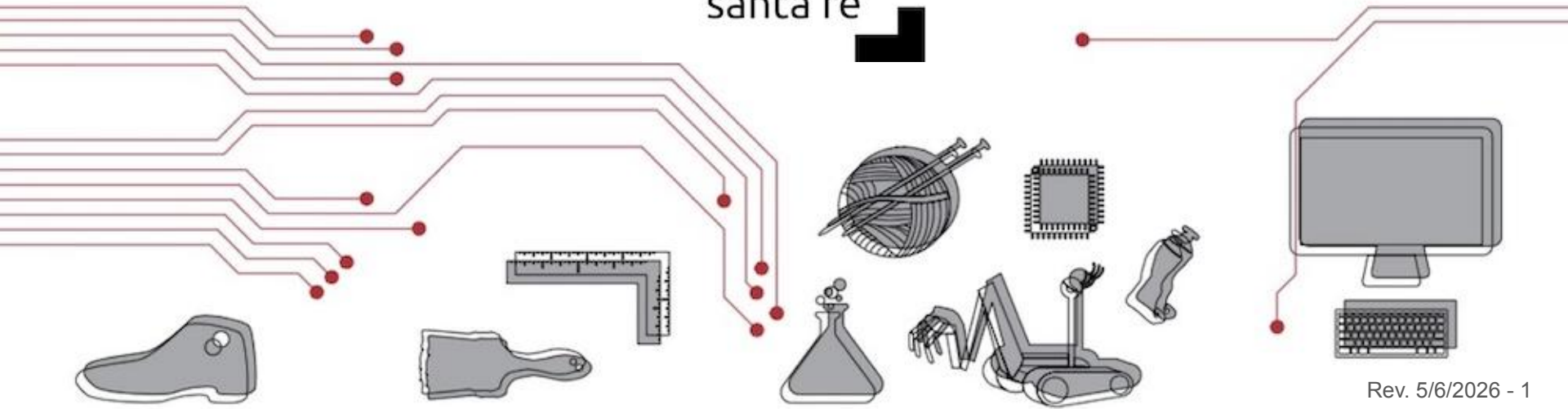
MAKE
santa fe



Welcome

- What projects do you want to explore?
- Experience with programming?
- Future areas of interest?
- Me: An electrical engineering and an MBA degree
- Interests: Microcontrollers, sensors, motors, batteries, internet of things, robotics, 3D printers, etc.
- Introduction: The self balancing robot and the grunt-bot

Class Overview

- Modern electronics is more about systems than components: micro-controllers, smart sensors, motors, LEDs, displays, radios (WiFi, Bluetooth)
- Even knowing what to search for can be difficult: ESP32, ESP8266, Arduino, Raspberry Pi, NeoPixels, LoRa, MicroPython
- This class goes deeper into microcontrollers, inputs (sensors), and outputs
- What motor should I use? DC, AC, stepper, servos?
- Which battery should I use? Size, type, charging
- Richard Feynman: Just learn what is needed to understand/solve problems

Basic Safety

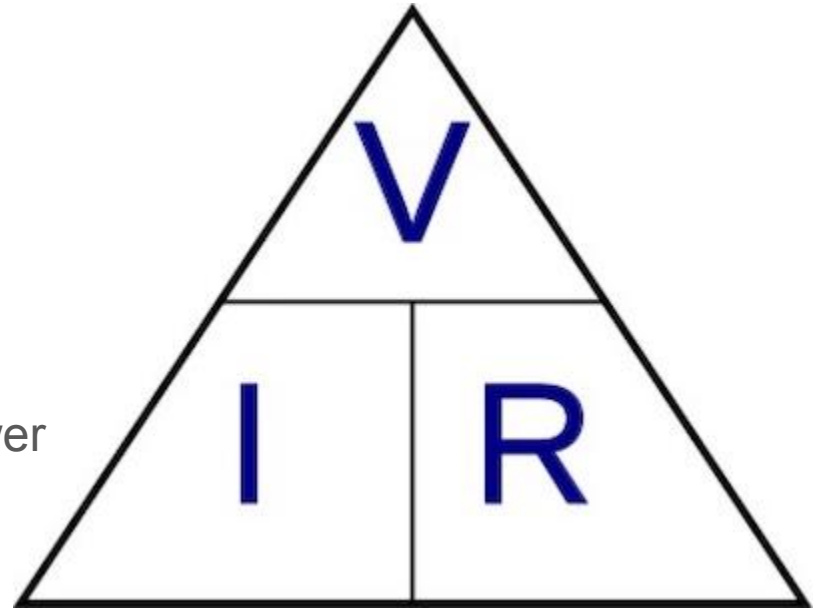
- One hand rule, buddy rule, capacitors, hot components
- Static grounding / Power ratings / Choosing wire size / Batteries

Voltage and Frequency

- Electrical equivalent of pressure (think garden hose)
- Measured between points (like water pressure or distance)
- Two different types: Direct and Alternating
- Alternating Current: Power outlet, AC power adapter
- Direct Current: Battery, Plug-in (AC to DC) adapter, USB ports, power supply
- Frequency is when voltage changes over time in cycles per second (Hertz)
- Sine waves / Square Waves / Pulse Width Modulation (PWM)

Voltage, Current, and Resistance

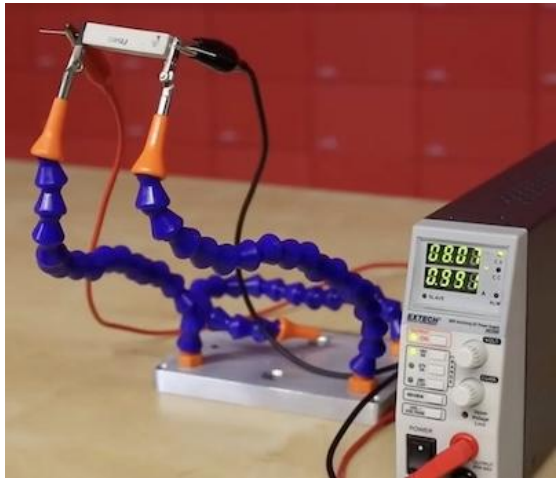
- Voltage = Current x Resistance
- Voltage is electrical pressure
- Current is the flow in amps (I)
- Resistance is the friction in ohms
- 5 volts = 1 amp x 5 ohms
- Ex. Used when calculating LED power



Power: Watts (P = V x I)

- Work done by the flow of electrons (amps) by pressure (voltage)
- 100W incandescent vs. 10W LED
- 1500W hair dryer plugged into 120V / 15A circuit
- Power rating of components
- An excellent explanation video

Watt Meter

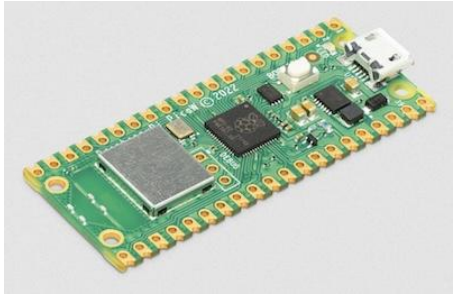


Spark Fun Video

Microcontrollers

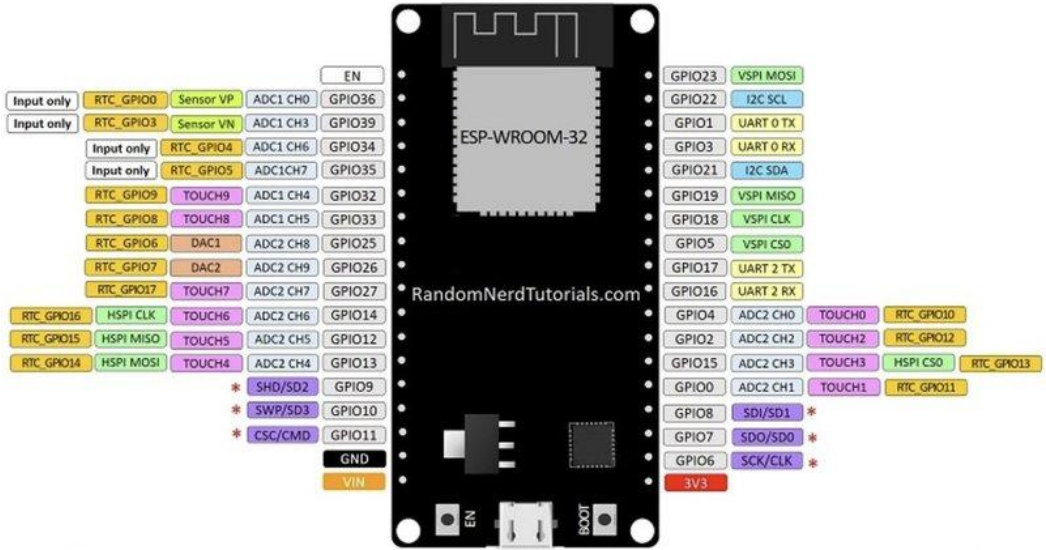
- Arduino / ESP32 - Open-source hardware / software electronics platforms intended for anyone making interactive projects
- Raspberry Pi - A credit card sized computer that can be used to learn coding and to build electronics projects, also works like a desktop PC
- And so many more! ESP32 variants, RP2040 (low-cost), STM32 (versatile), and Nordic nRF series (Bluetooth). Other types.

STM32 - power efficiency, superior precision, and real-time performance



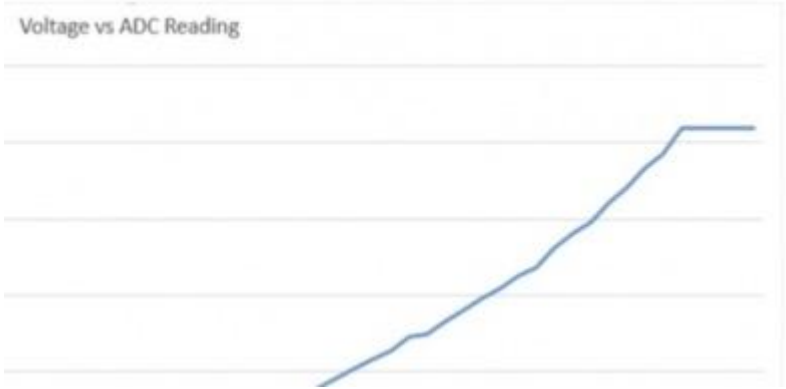
ESP32 Tips and Tricks

- Choose the right pins by referencing this tutorial
- Safe pins for input AND output: 13, 18, 19, 21, 22, 23, 25, 26, 27, 32, 33
- More ESP32s / YouTube video
- Digital to analog pins: 25 and 26
- Analog to digital pins: 34 to 39
- Using WiFi, don't use ADC2
- 34, 35, 36, 39 are input only
- 32-33 are always input/output?
- So much for General Purpose I/O
- Always triple check (Make Wiki Page)



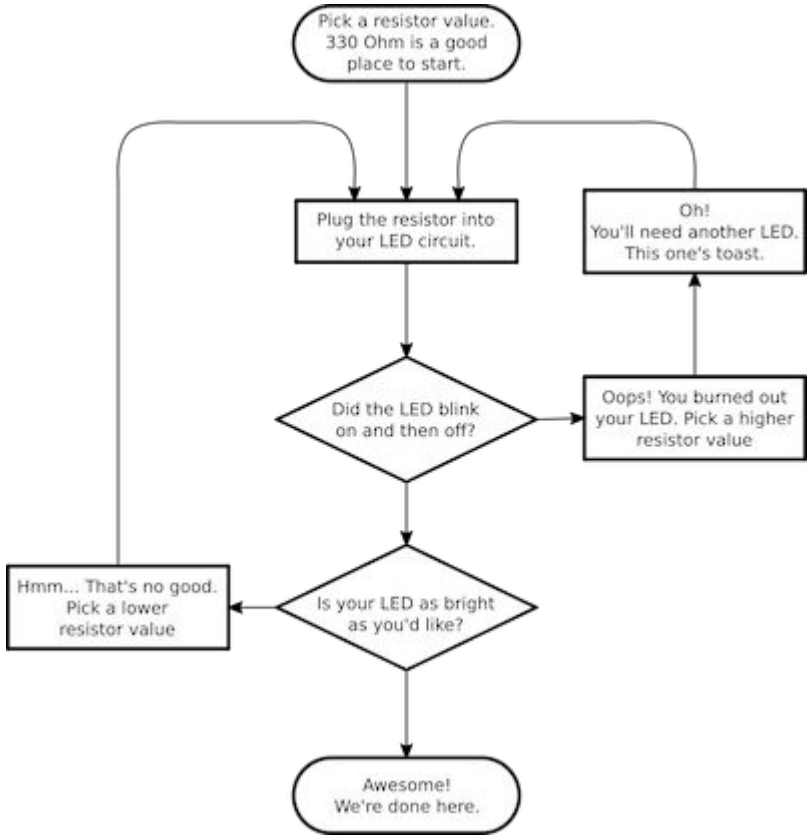
Analog Inputs

- Pushbutton - Pull up and pull down resistors
- Voltage inputs - Analog to digital converters (ADC), battery voltages (3.3v)
- Higher voltages - Voltage dividers
- Current measurement - Current shunt (precision, low-resistance resistor)
- Potentiometers - A type of voltage divider
- ESP32: issue with reading 3.3v vs 3.2v
- STM32s have better ADCs



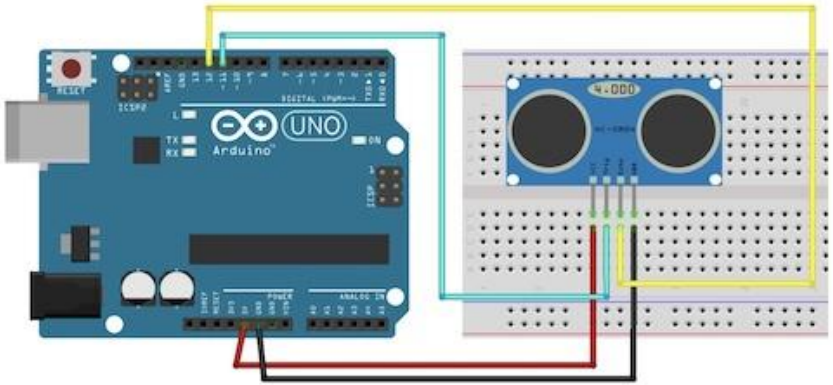
Analog Outputs

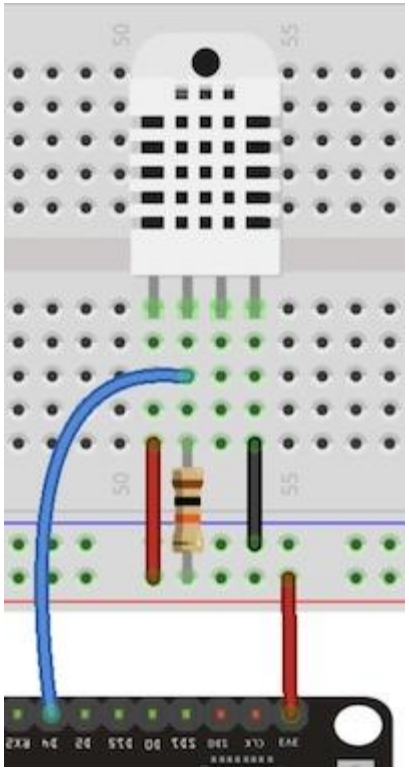
- LED - One color for each LED and needs a current limiting resistor
- Beeper/Buzzer - This can also be a low quality speaker
- PWM - LEDs, position servos, speed control for DC motor controllers



Digital Inputs

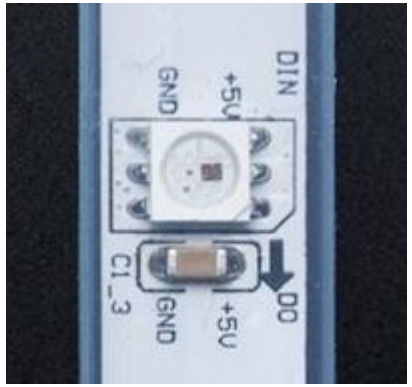
- I2C bus (Inter-Integrated Communication) guide
- SPI bus (Serial Peripheral Interface) guide
- Temperature and humidity sensor DHT22
- Distance pulse length sensor HC-SR04

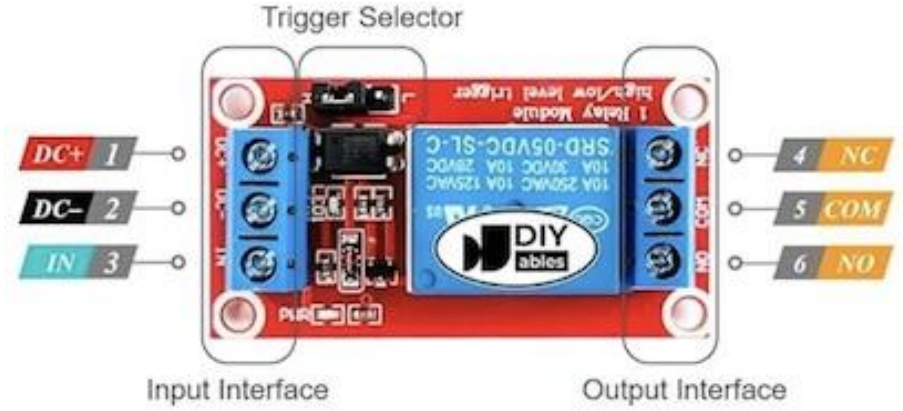


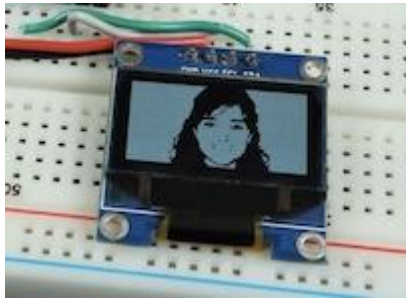


Digital Outputs

- Neopixel LED guide and a more technical guide
- LCD Displays - Two line display guide (I2C)
- OLED Displays - SSD1306 guide
- Mechanical and solid state relays (SSRs)

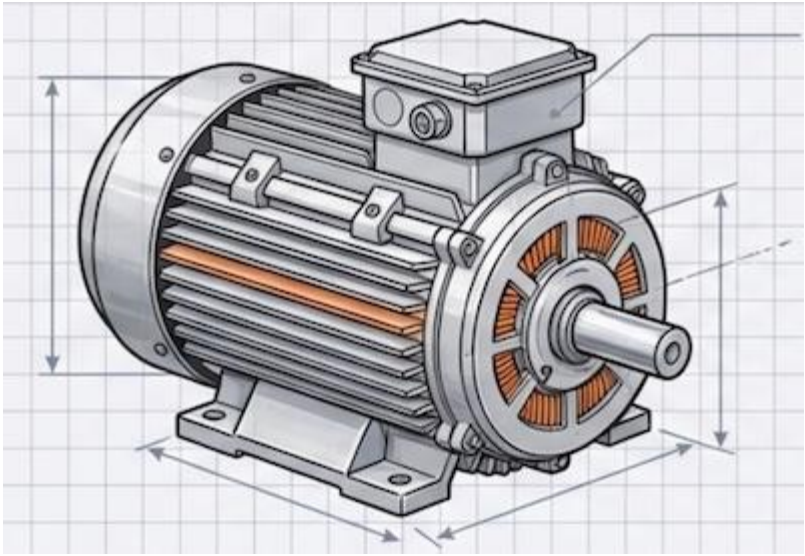






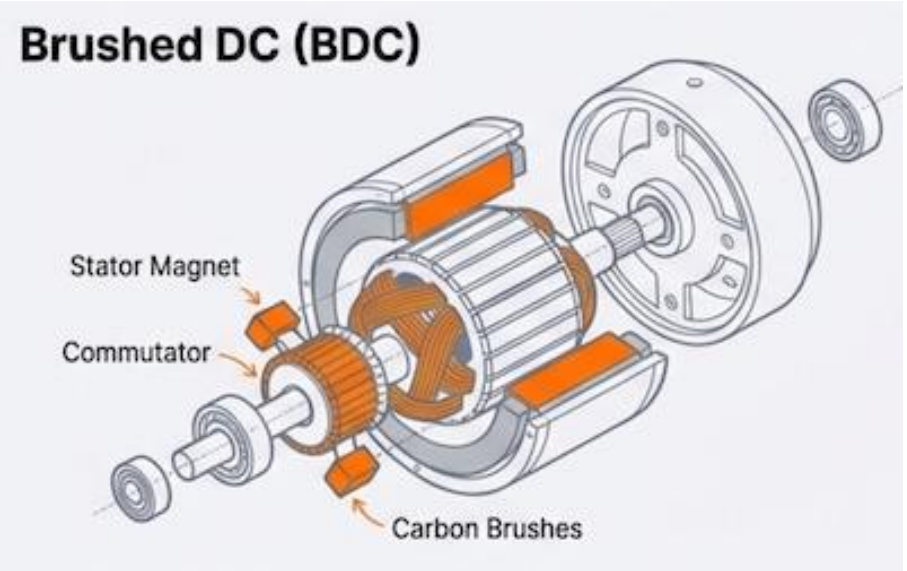
Alternating Current Motors

- Usually higher horsepower
- Synchronous (Induction) and Asynchronous
- High power efficiency and durability
- Air conditioners, industrial machinery, CNC machines, power tools
- A video on how they work



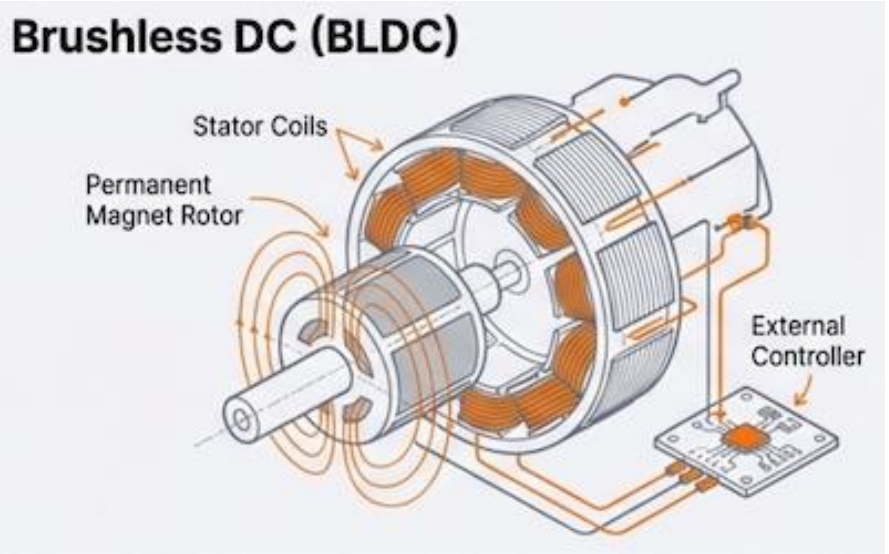
Direct Current Motors

- Electromagnetic induction via stationary carbon brushes and rotating commutator
- Low cost, simple control, and good low-speed torque
- But physical wear issues, electrical interference, heat, and maintenance requirements
- Good for smaller projects where speed/direction control is important - Video 1, 2, and 3



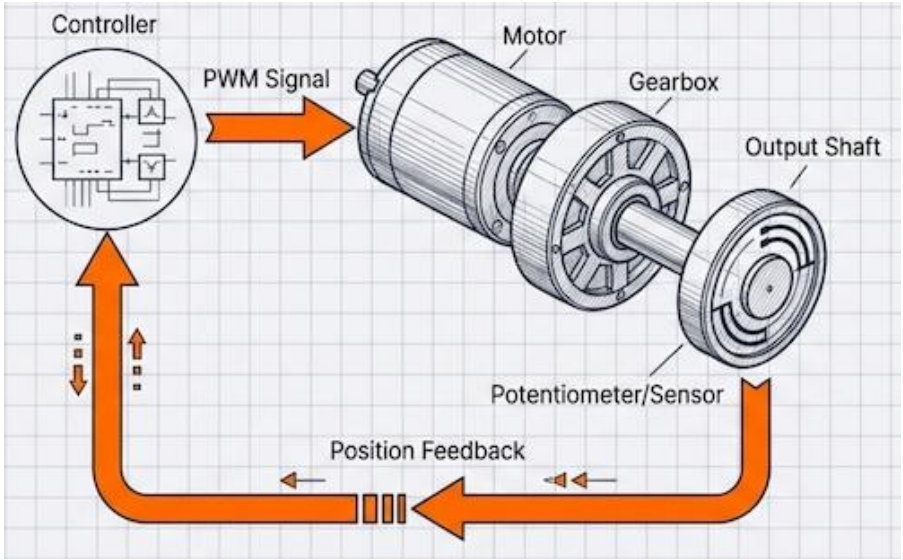
Brushless Direct Current Motors

- Electronic commutation (external controller), permanent magnet rotor, electromagnet stator
- High efficiency, low heat, quiet, long lifespan, precise control
- But higher cost, requires complex controllers (ESCs) and sensors
- Good for drones, automotive wipers/seats, appliances, cooling fans, power tools, EVs
- Excellent video 1 or 2 or DIY it



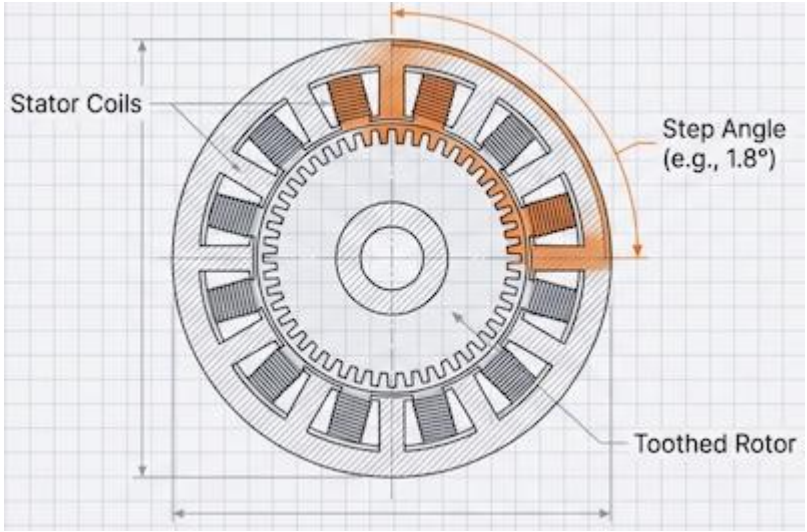
Servo Motors

- Uses a feedback sensor (encoder) and control circuit
- Receives PWM signals to target specific angles
- Continuously corrects deviations to hold position under load
- Exceptional accuracy in speed, torque, and position
- But higher complexity/cost and most limited to 180° rotation
- Video



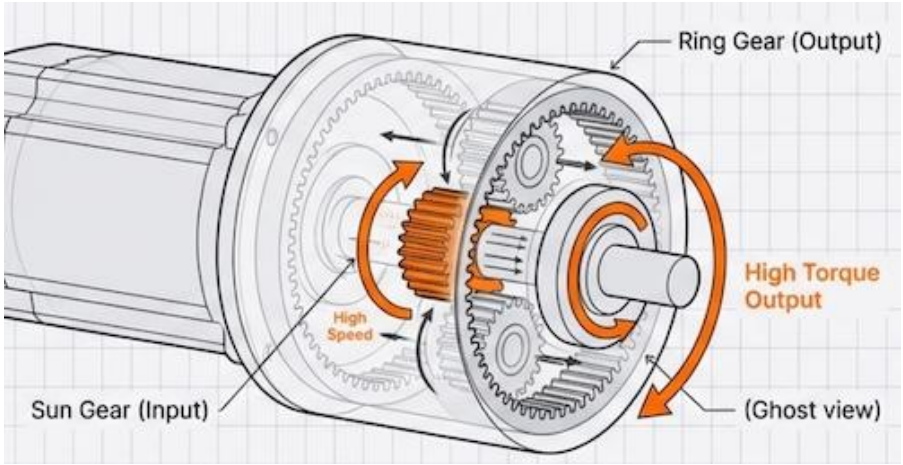
Stepper Motors

- Stator coils energized in sequence to attract rotor's magnetic teeth
- Operates on open-loop control
- Known for holding Torque: holds position firmly when energized
- High precision/repeatability, stable at low speeds
- But uses power when stationary and risk of resonance
- 3D printers, CNC machines, telescopes - technical paper



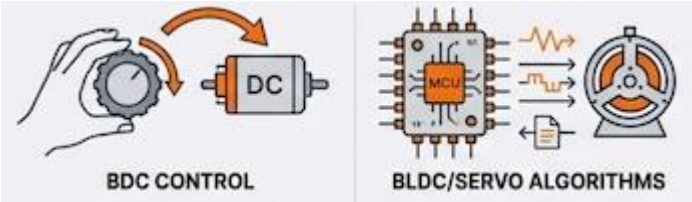
Gearboxes for Motors

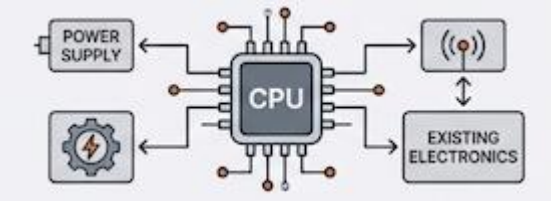
- Allows a compact motor to move a heavy load
- Reduces rotational speed while significantly increasing output torque
- Many types: Planetary, Spur, Worm, Helical
- Can be 3D printed
- Often combined into a "gear motor" assembly to optimize space and efficiency



How to Select

- Torque, Speed, Accuracy, Power efficiency, Budget
- Power / size weight balance: Drones need light motors that can run a long time, cars not so much
- Ease of control: DC motor controller versus electronic speed control module for BLDC
- Environmental factors: Moisture, dust, temperature
- Explanation video





Summary

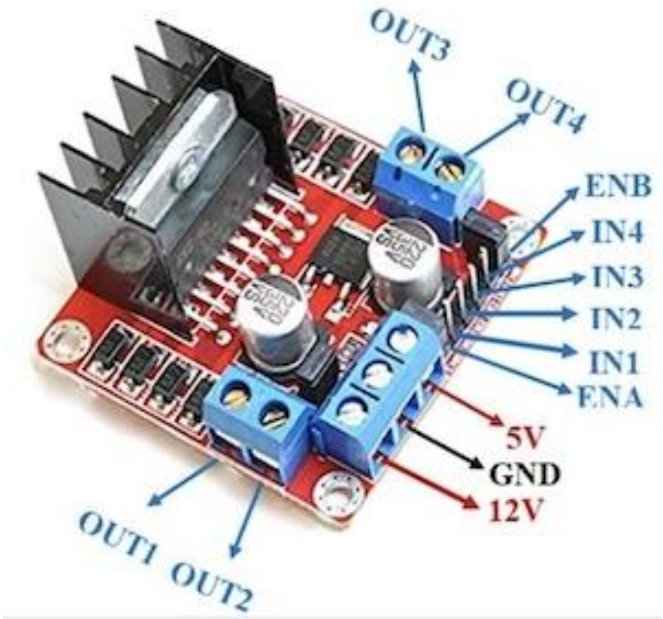
- Ohm’s Law (V=I×R) which relates voltage (pressure), current (flow), and resistance (friction) while Power (P=V×I) is the work performed by electrons
- Arduino and ESP32 are open source, Raspberry Pi is the credit-card-sized computer, and the STM32 is great for low power and real-time performance
- Analog I/O for variable voltage inputs, PWM for motors, Digital I/O using protocols such as I2C and SPI for digital sensors and OLED displays
- Brushed DC motors for low-cost projects, Brushless DC (BLDC) for high efficiency, Servos for precise position control, and Steppers for high repeatability and holding torque
- Practicing the demos that apply to your project is a great way to learn

What Should We Do Next?

- Data collection, management, representation?
- USB-C power
- Batteries
- DC voltage conversion and management
- Programming resources
- Where to go from here
- Or quit yer yapping and let us do some hands-on!

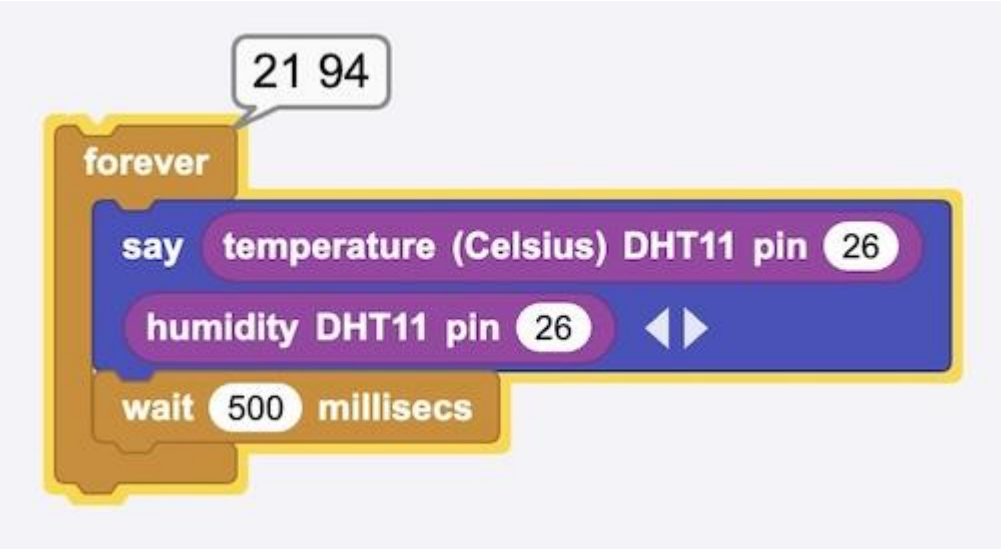
But first… Troubleshooting

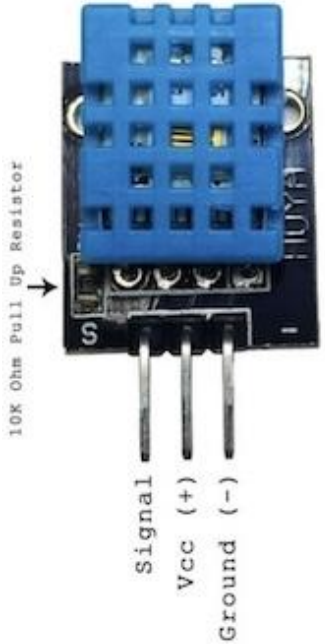
- Requires a systematic approach
- Break down and simplify the problem by isolating parts
- Review the spec/data sheets, confirm inputs, confirm outputs
- Test power to motor then test motor then test connections
- There’s a whole book on it



Temperature and Humidity Sensor Demo

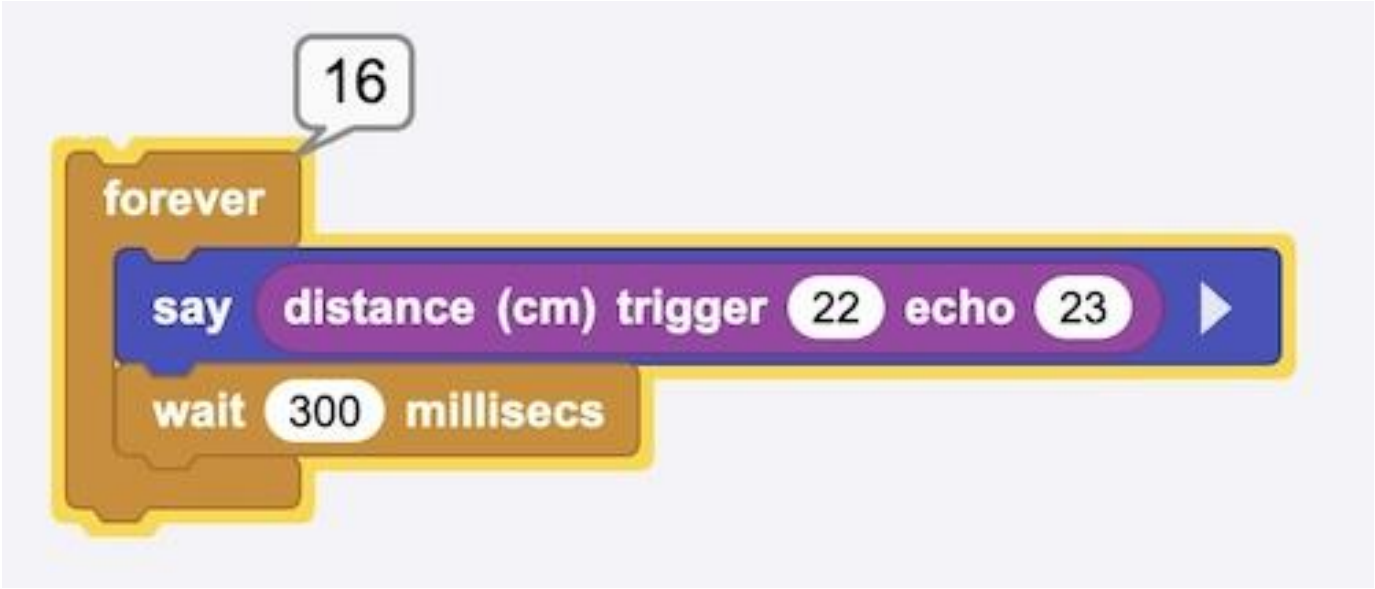
- Do not use pins that are “input only” (34, 35, 36, 39)
- Triple check pinout (varies between manufacturers)





Distance Sensor HC-SR04 Demo

- Ultrasonic with a wide sensing “aperature” and up to 15 foot distance
- ESP32 requires the [3.3v version] of this sensor
- Otherwise connect power, ground, trigger, and echo to ESP32

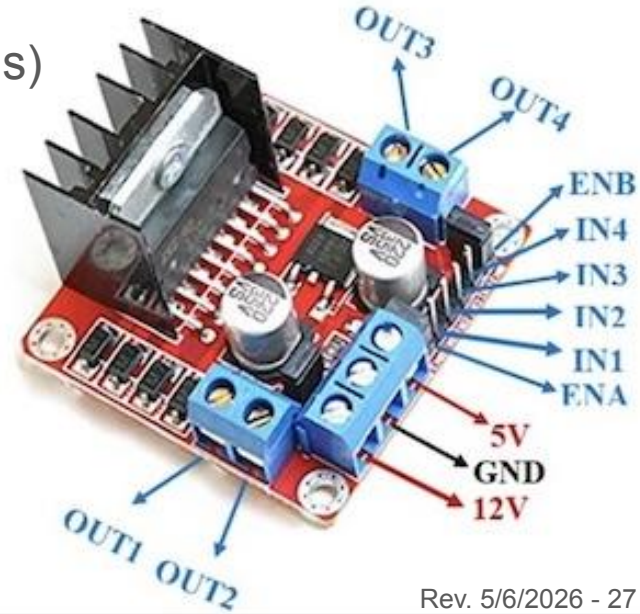


Joystick (Potentiometer) with Push Button Demo

- Need to use pins that have an ADC (25, 26, 27, 32, 33, 34, 35, 36, etc.)
- Pushbutton connects pin to 5v so need a pullup resistor (internal)
- Outputs 0 to 1023

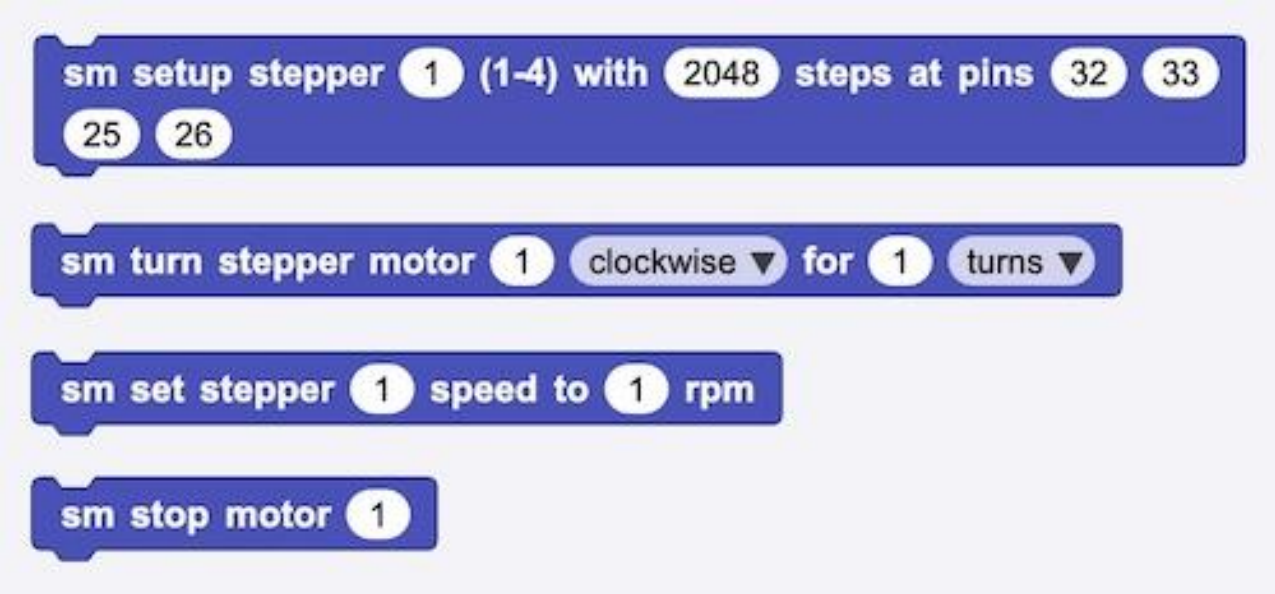
DC Motor with Controller Demo

- L298N can control two motors' speed and direction up to 25 watts
- ENA/B is a PWM speed input while IN1 and IN2 control direction
- IN1 and IN2 on OR off stops the motor
- Tutorial to choose the right power pins (not obvious)
- Motor might not turn at lower PWM values



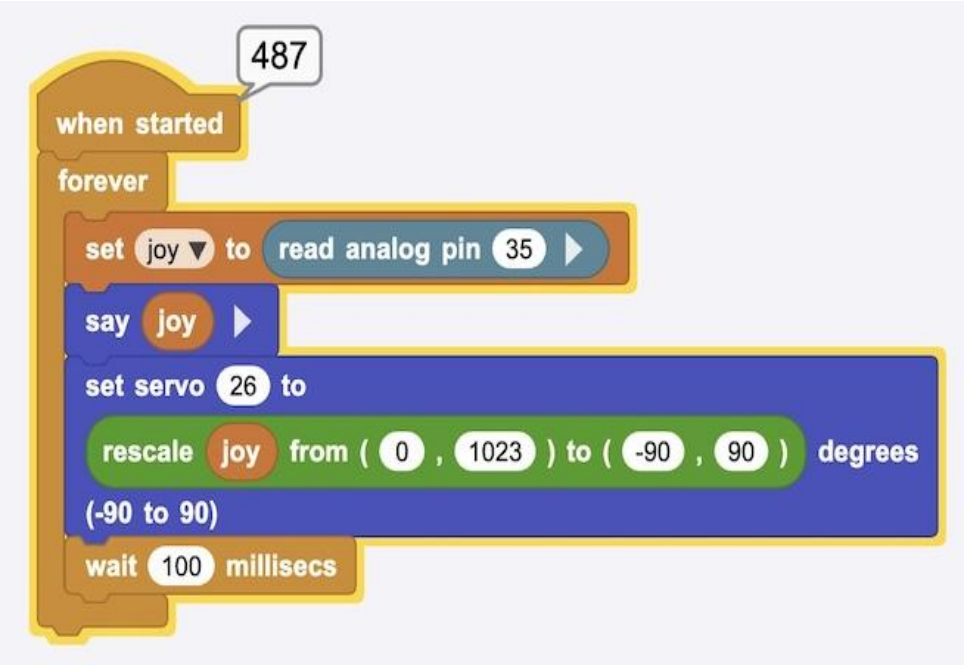
Stepper Motor Demo

- Connect IN1, IN2, IN3, IN4 to output pins
- Connect +5v and GND to power area of breakout board



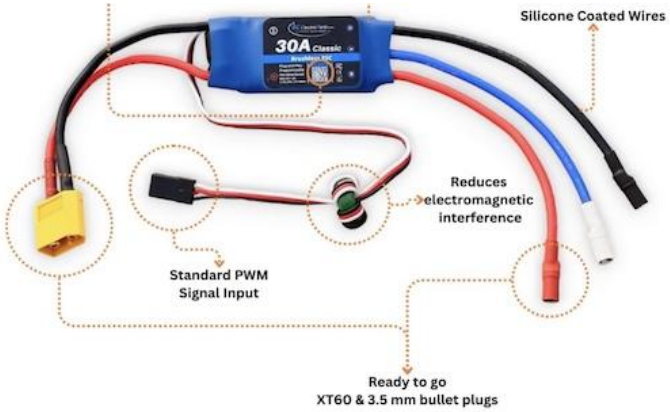
Joystick and Servo Demo

- Can connect small servos to the ESP32 directly (needs 5v power)
- Connect joystick to pin 35: 3.3v to “+5v” pin, GND, VrX or VrY
- Output of Say (Analog Pin 36) should be around 500
- Connect servo to pin 26: Red (5v), Brown (Gnd), Orange (Signal)



Brushless DC Motors

- Requires three wire Electronic Speed Controller (ESC) board
- Most need a "zero" signal for a few seconds before starting for safety reasons
- Control via [PWM signal]



The Data Collection and Management Rabbit Hole

- Node-RED graphical programming tutorial and another tutorial
- Particle Photon 2 board with access to the “IoT Platform-as-a-Service”
- Adafruit’s IoT for Everyone and Wippersnapper - DC current/voltage example
- “How to Log Data 10 Different Ways” tutorial

USB-C Power

- Unlike USB-A the voltage can vary and be negotiated with a trigger board
- Standard voltage steps are 5 V, 9 V, 15 V, 20 V, and 28V
- Formal name is USB-C Power Delivery
- Qualcomm has a proprietary standard called QC
- Experimental boards: HUSB238 and ZY12PDN
- A more complete guide and a video

Batteries

- Lithium Ion (Li-ion) - Good general rechargeable, usually cylindrical. Found in phones, laptops, flashlights, etc.
- Lithium Polymer (LiPo) - Higher discharge rate, usually rectangular or pouch shaped
- Lithium Iron Phosphate (LiFePO4) - Heavier, 0%-100% every day, 2000+ charge cycles (vs 500), good for solar battery systems

Basis	Lithium Ion	Lithium Polymer
Ageing	Loses actual charging capacity over time	Retains charging capacity better than Lithium =ion
Energy Density	High Energy density	Low as compared to lithium ion
Conversion Rate	The capacity to convert battery into actual power 85-95%	75- 85%
Safety	More Volatile as compared to lithium polymer	More safety. Less chance of explosion
Cost	Cheaper	Slightly Expensive(+30%)
Weight	Heavier	Light Weight
Charging duration	Longer Charge	Comparatively Shorter

DC Voltages - Conversion and Battery Management

- Buck converter for higher to lower (5v-30v to 5v 1.8amps)
- Boost converter for lower to higher (2v-24v to 5v-28v 2 amps)
- Battery charging and discharging is a complex topic
- Many terms like 1S-6S, “C” ratings, balance chargers, etc.
- Several useful tutorial like how to charge, mastering charging, and how to charge correctly and safely
- Could be a class on it’s own but in general managing charging voltage and current during charging is critical so best to use a commercial charger

Programming Resources

- MicroPython: Requires firmware/IDE (Thonny). Use AI and tutorials to learn.
- Web based Arduino IDE (code editor) where you can write code, access libraries, and upload to boards (ESP32 and other boards as well). Tutorials are available, a language reference, and a “cookbook.”
- Hardware is needed and kits are the least expensive option. This kit includes an ESP32, sensors, relays, and even an OLED display for $20.

Where to go from here?

- The Make Santa Fe electronics wiki page
- Create a PCB to get rid of the breadboard $25 for 5
- Requires design skills (KiCad) and soldering skills - advanced tutorial video or maybe the ElectroCookie?
- Learn the standard messaging IoT Protocol MQTT
- Use simulation before building a project with Wokwi
- Learn Linux for embedded system with the Yocto Project
- Explore even more ESP32 variants in this video