Electrics & Microcontrollers: Inputs+Outputs
Sensors, Motors, and Batteries for Makers

Paul Sakion

MAKE
santa fe
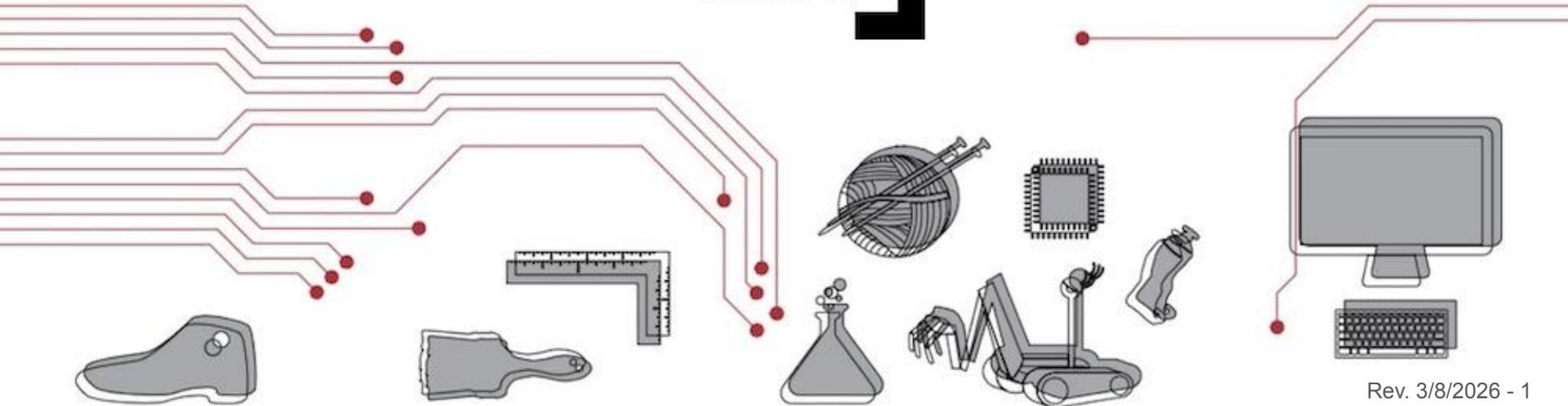
Welcome

- Experience with programming?
- What projects do you want to explore?
- Other areas of programming of interest in the future?
- I have an Electrical engineering and an MBA degree
- Interests include microcontrollers, sensors, batteries, robotics, internet of things, 3D printers, and more
- Introduction: The self balancing robot and the "grunt-bot"

Just Enough Electronics

- One hand rule, buddy rule, capacitors, hot components
- Static grounding / Power ratings / Wire sizes / Batteries
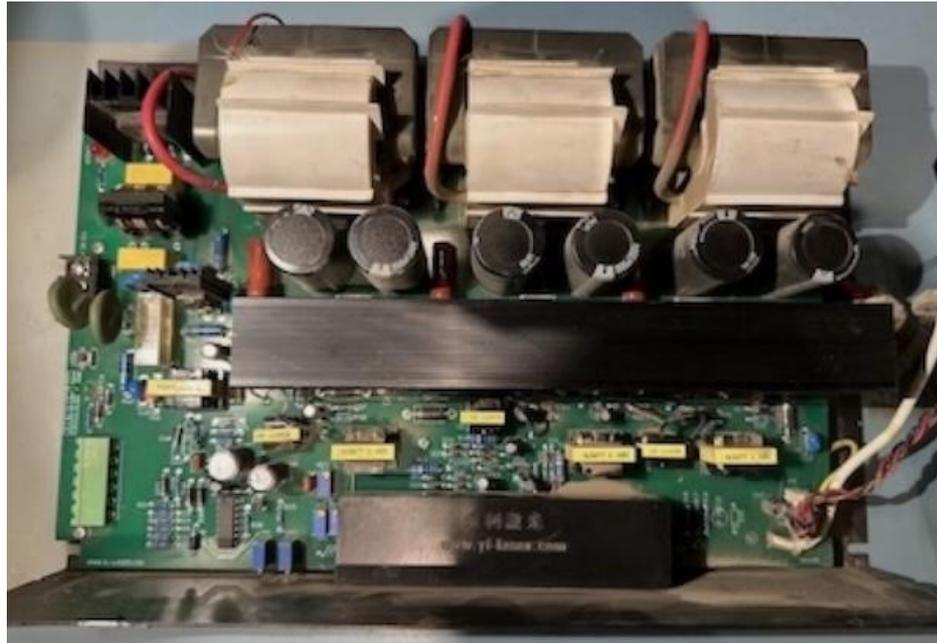
Voltage and Frequency

- 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)

Ohm's Law

- Voltage = Current x Resistance
- Voltage is electrical pressure
- Current is the flow in amps (I)
- Resistance is the friction in ohms
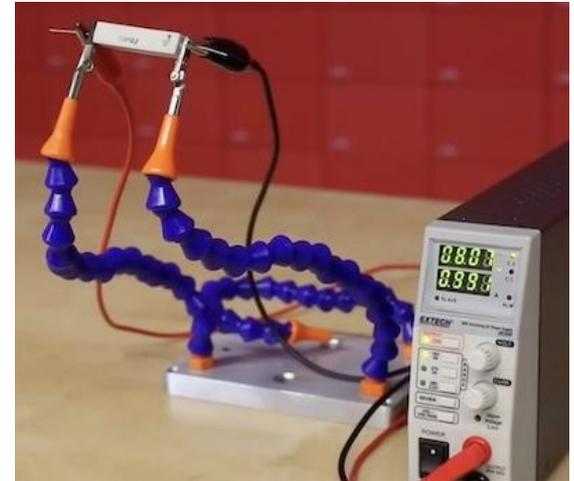- 5 volts = 1 amp x 5 ohms
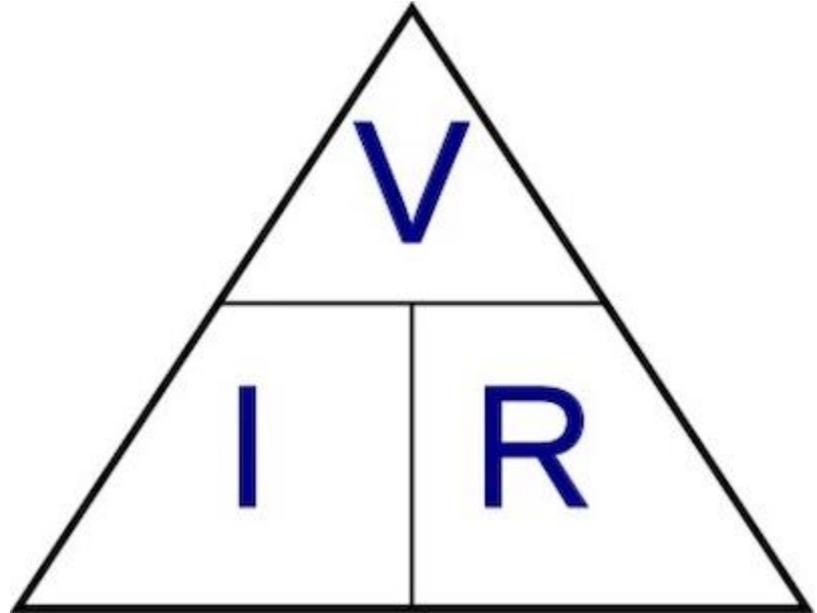
Power: Watts (P = V x I)

- 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)

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

ESP32 Tips and Tricks

- Avoid the forbidden 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](#)
- Pinout changes by model
- ADC Pins: 25, 26, 27, 32, 33
- BUT 25, 26, 27 are for WiFi!
- SO 32-36 & 39 are ok for analog
- So much for "GPIO!"
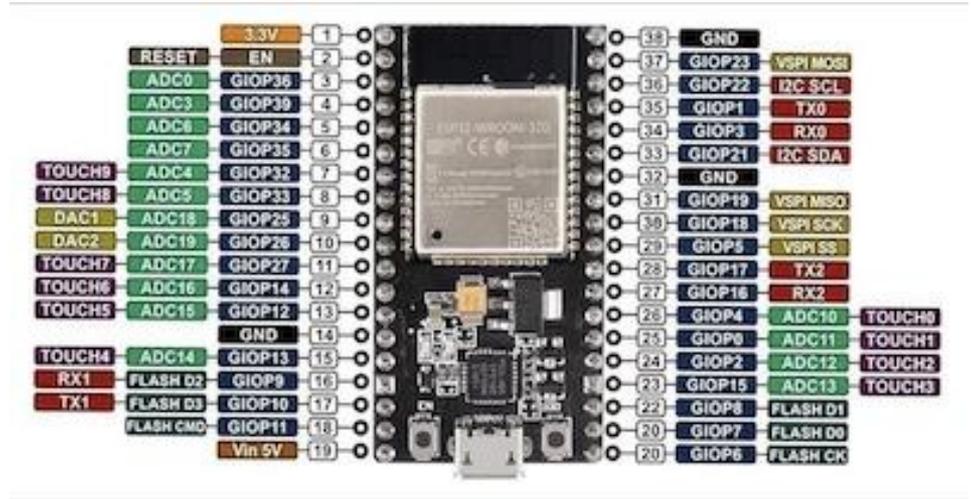
Analog Inputs

- 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: reading 3.3v vs 3.2v issue
- STM32s have better ADCs

Voltage vs ADC Reading

Analog Outputs

- LED - One color for each LED and needs a current limiting resistor
- Beeper/ Buzzer - Use this for "maximum irritation"
- PWM - LEDs, Position servos, Speed control for DC motor controllers
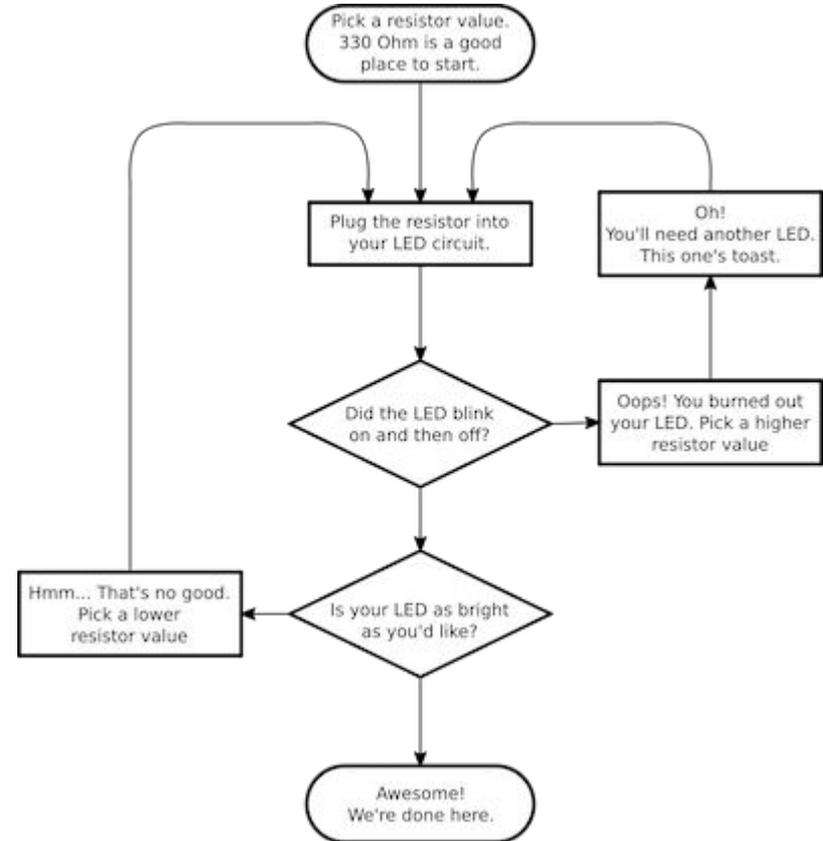
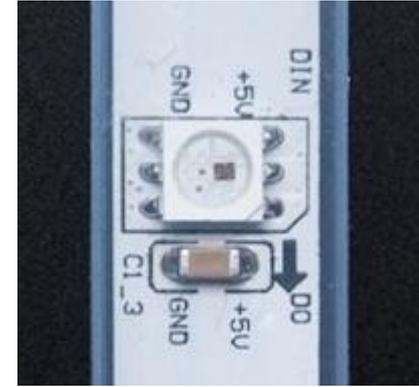# Digital Inputs

- Inter-Integrated Communication (I2C) - ESP32
- SPI - ESP32 Guide
- Temperature / Humidity - DHT22
- Distance - Pulse length sensor
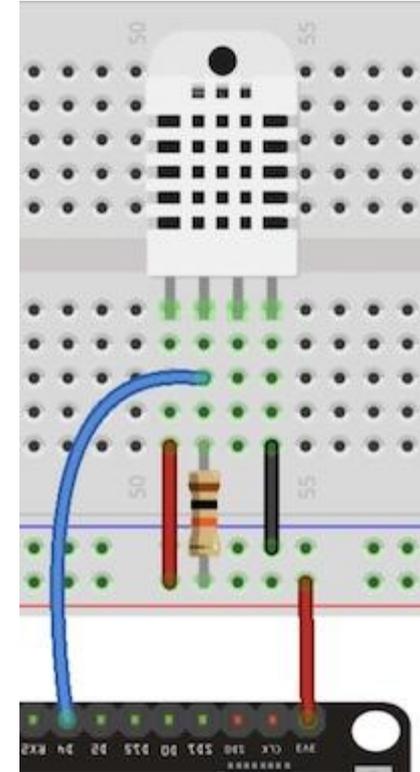
Digital Outputs

- Neopixel LEDs - Guide / more technical guide
- LCD Displays - Two line display guide (I2C)
- OLED Displays - SSD1306 guide
- Relays - Mechanical / solid state relay (SSR)
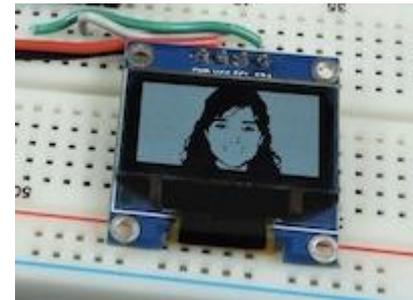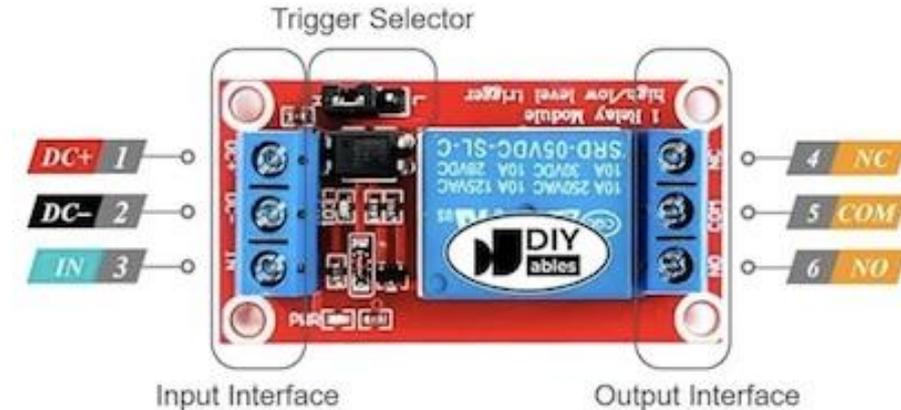
Alternating Current Motors

- 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
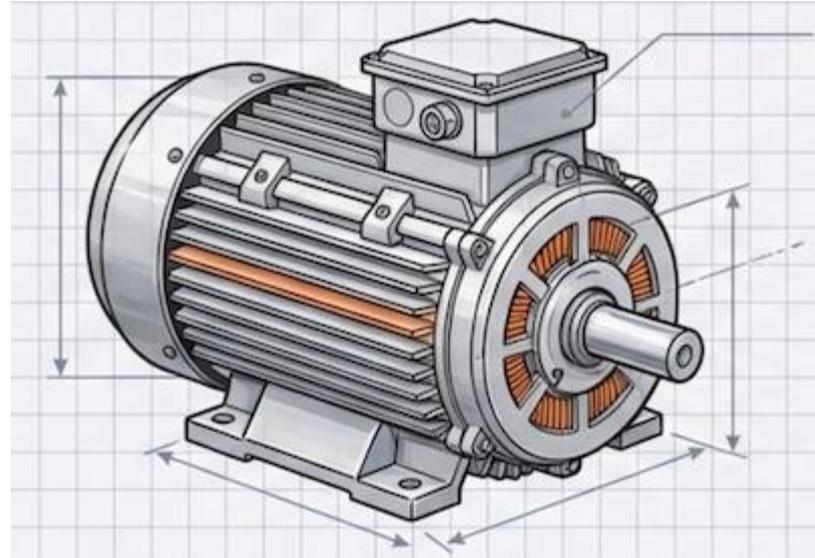
# Direct Current Motors

- 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

Brushed DC (BDC)

Stator Magnet

Commutator

Carbon Brushes
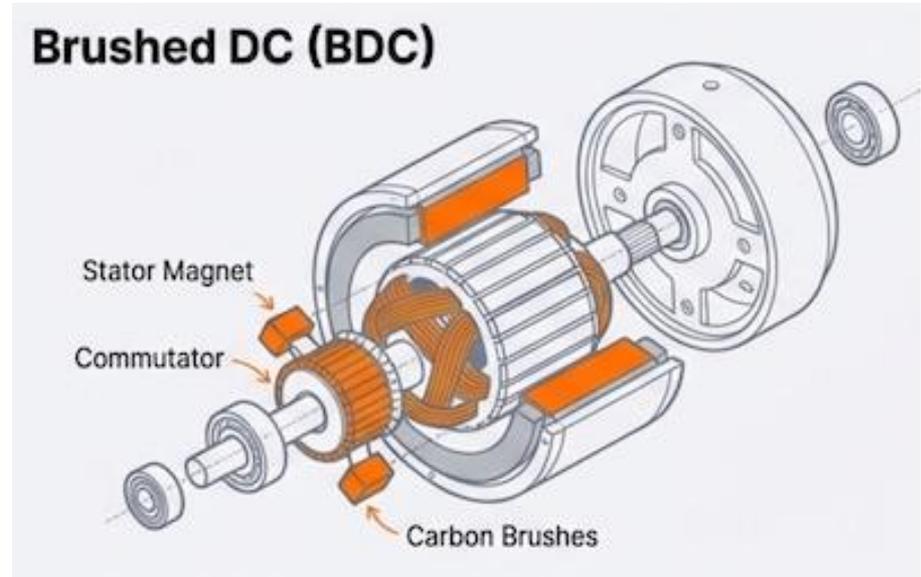
Brushless Direct Current Motors

- 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](#) or [make your own](#)

Brushless DC (BLDC)

Stator Coils

Permanent Magnet Rotor

External Controller
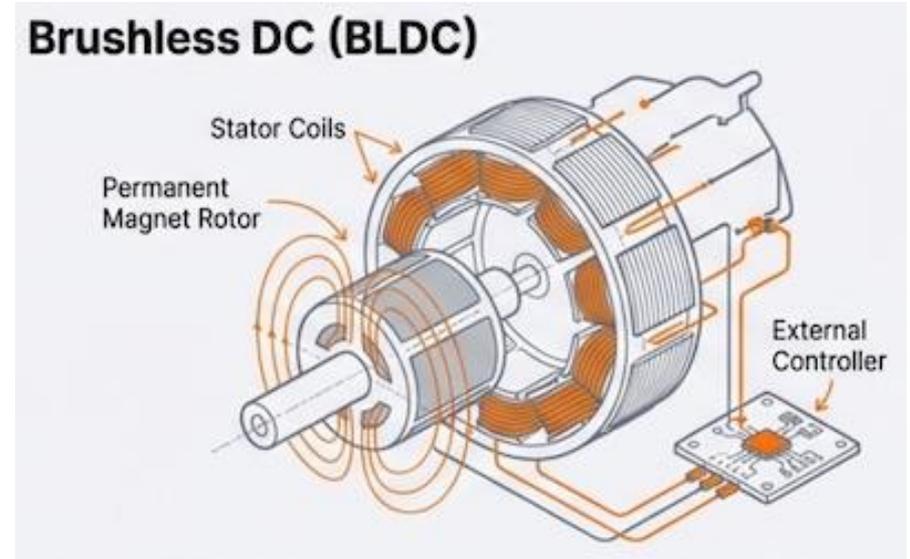
Servo Motors

- 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
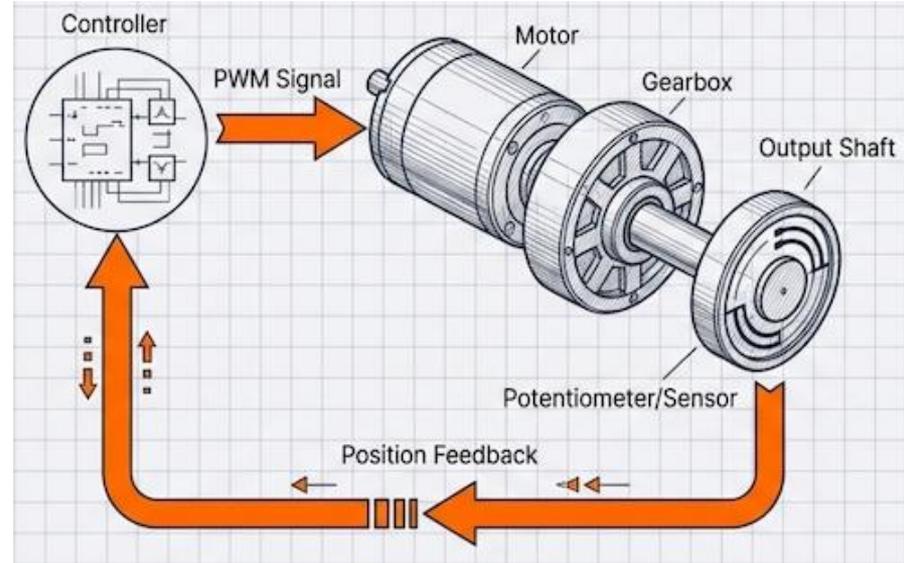
Stepper Motors

- 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
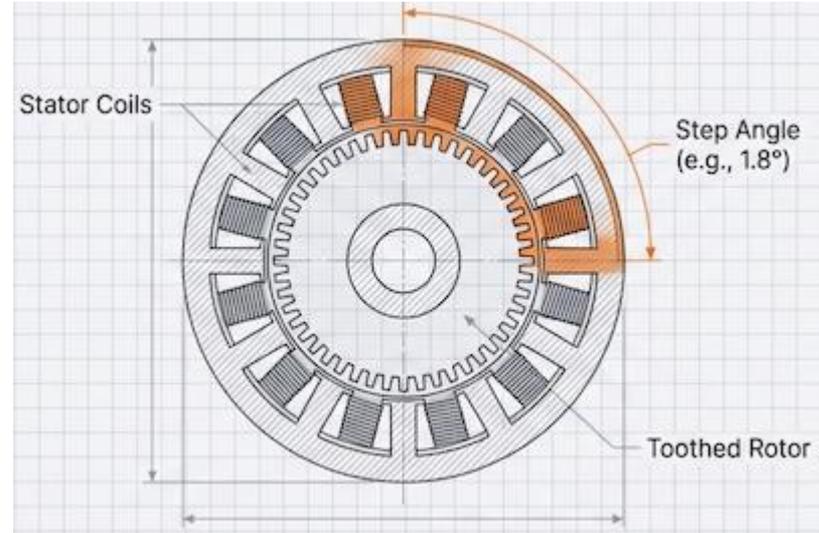
Gearboxes for Motors

- 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
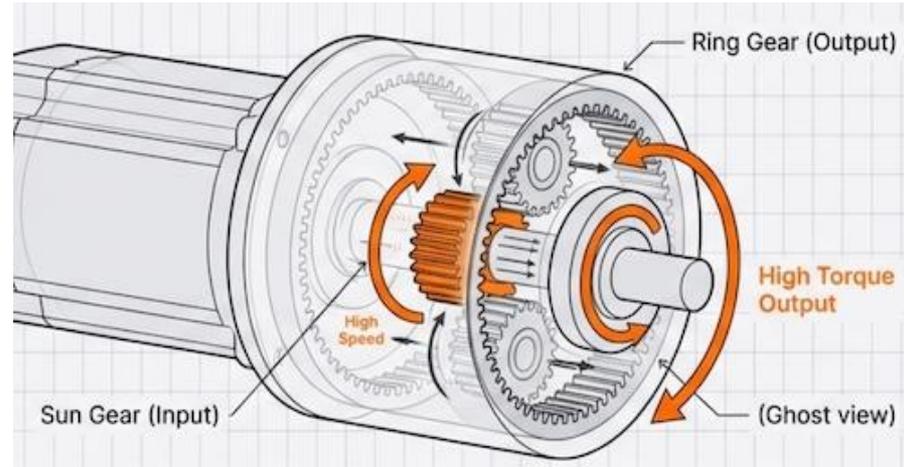
How to Select

- 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
- System integration: Compatibility
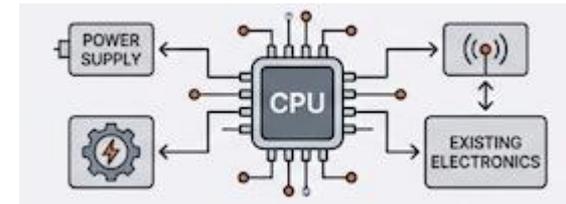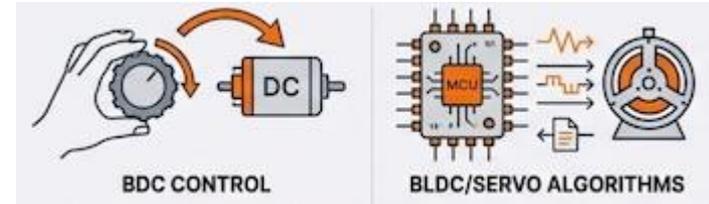
The Data Collection and Management Rabbit Hole

- Node-RED graphical programming [tutorial](#) and another [tutorial](#)
- Particle [Photon 2](#) [board](#) with access to the "IoT Platform-as-a-Service"
- Adafruit "[IoT for Everyone](#)" [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 - QC
- Experimental boards: HUSB238 and ZY12PDN
- A more complete guide can be found here 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.

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
- Practice the demos that apply to your project

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](#)

Let's do some hands-on!
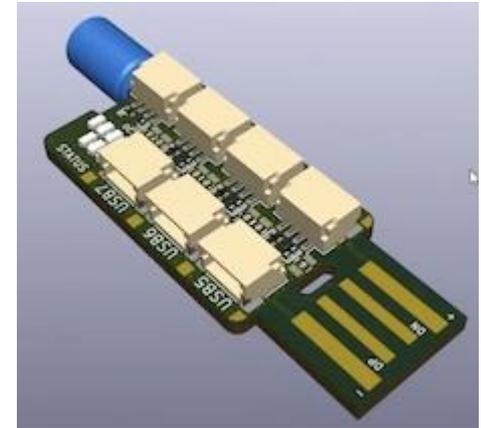
Temperature / Humidity Demo

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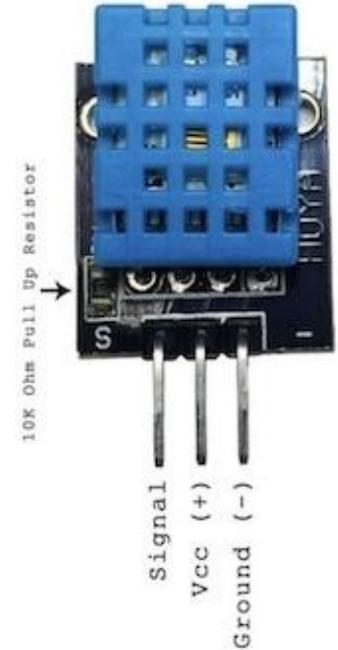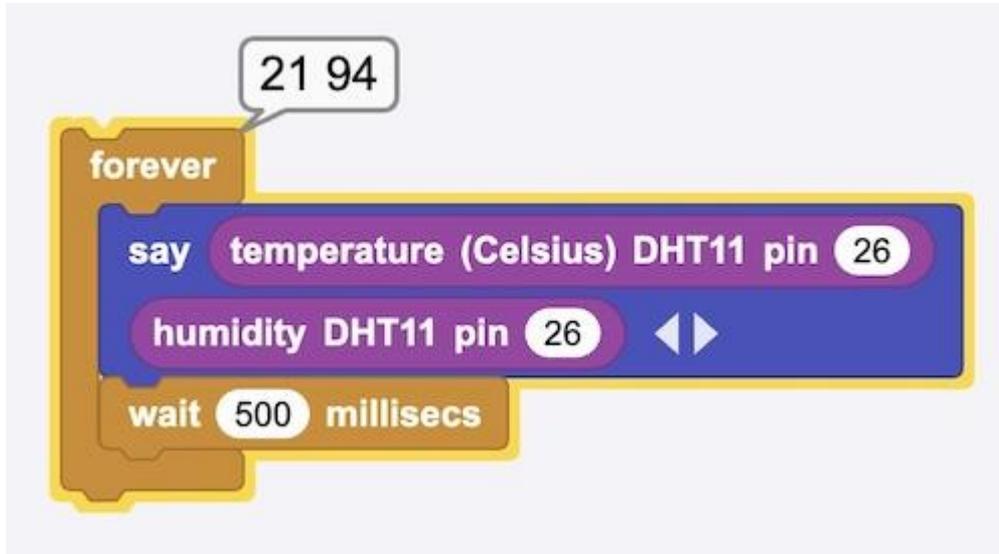
Distance Demo

- ESP32 requires the 3.3v version of this sensor
- Also can use I2C, 1Wire, or UART for some models (solder the jumper)
- Otherwise connect power, ground, trigger, and echo to ESP32

Potentiometer / Push Button (Joystick) 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 / 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
- [Power jumper](#) is important for higher voltages
- Motor might not turn at lower PWM values
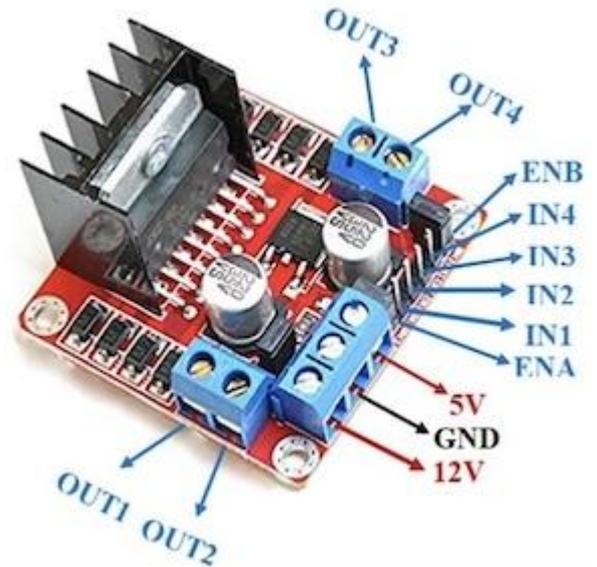
Stepper Motor Demo

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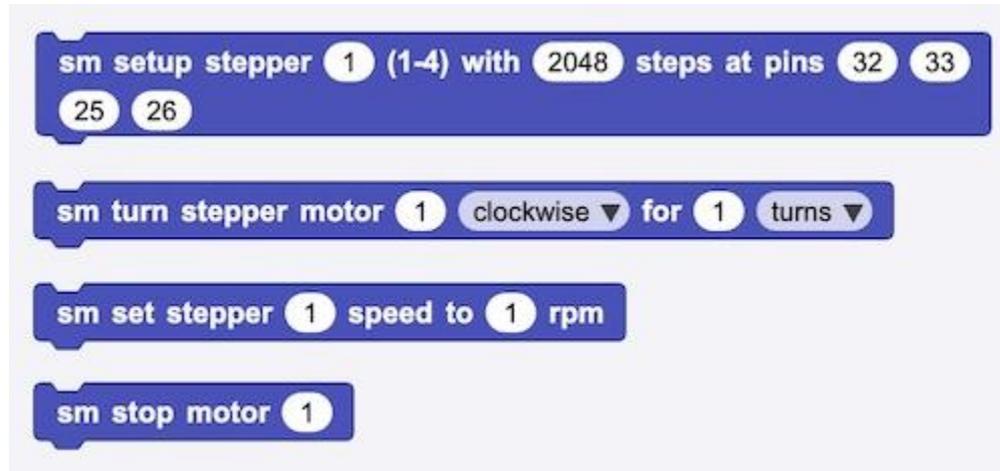
Servo Motor Demo

- 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)
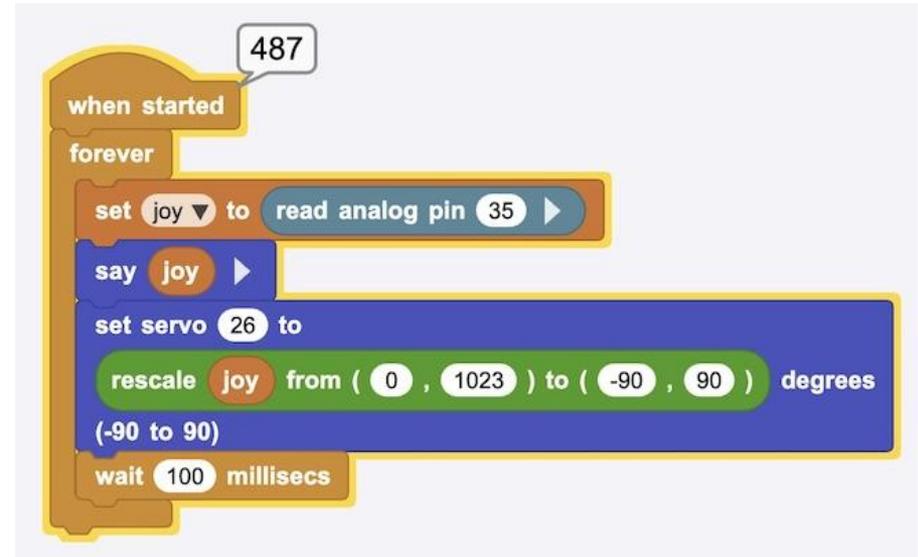
Brushless DC Motors

- 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

Silicone Coated Wires

Reduces electromagnetic interference

Standard PWM Signal Input

Ready to go XT60 & 3.5 mm bullet plugs