

HOW TO PROTOTYPE (ALMOST) ANY CIRCUIT

from the perspective of designer and maker

by Yuxiang Cheng

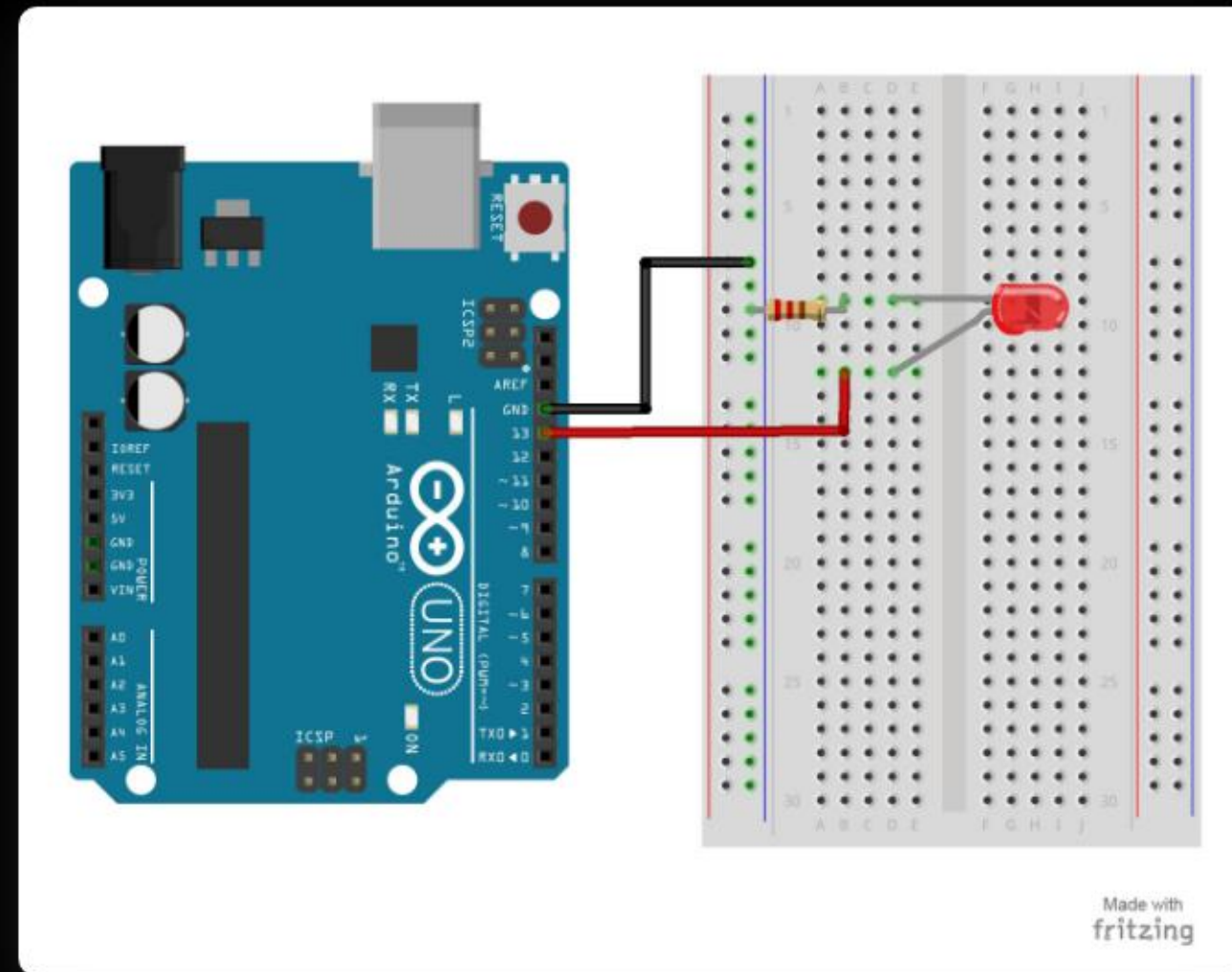
Part 1

EE Speedrun

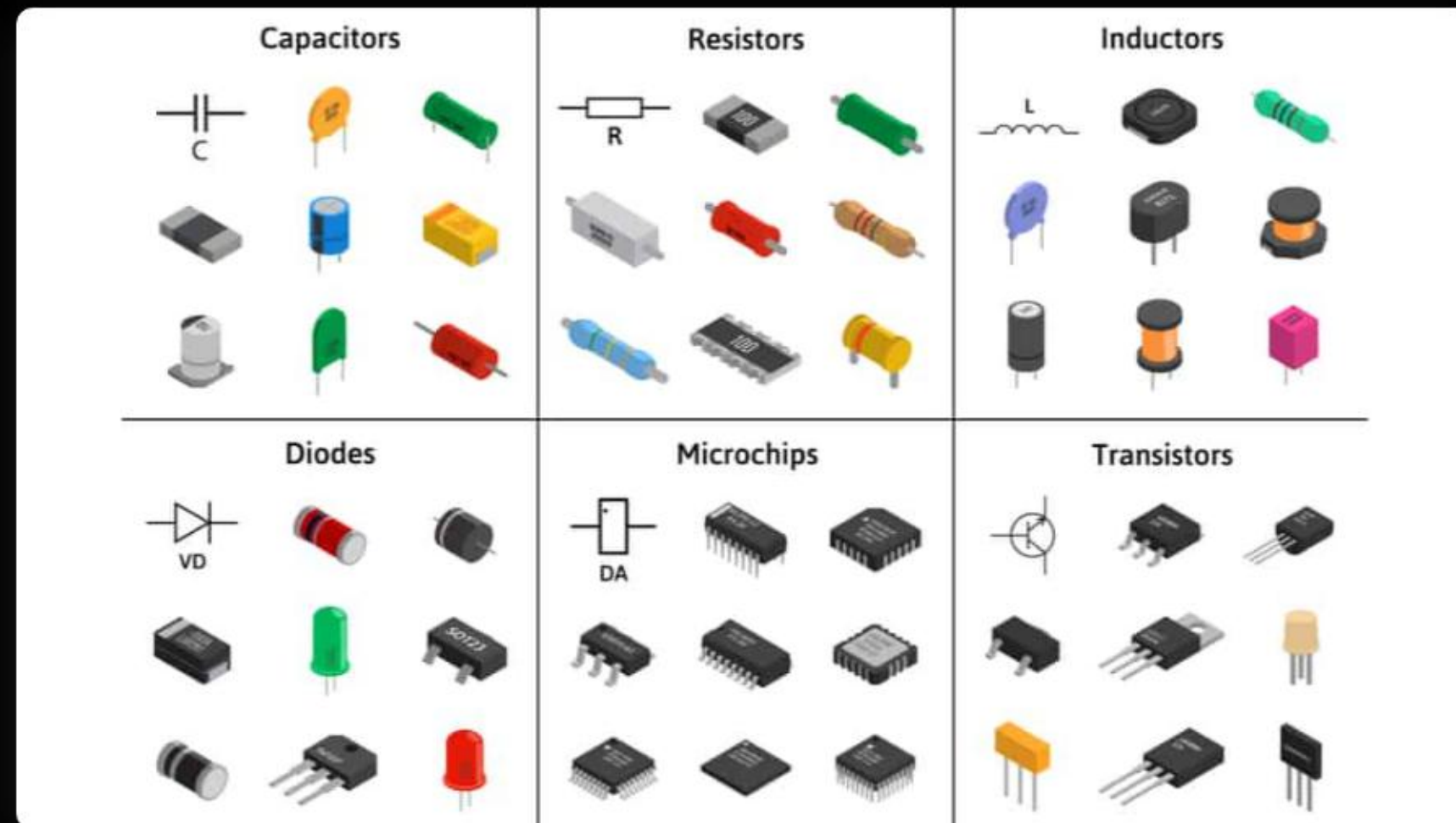
"All computing is physical."

-- Tom Igoe

We have all played with this



Parts

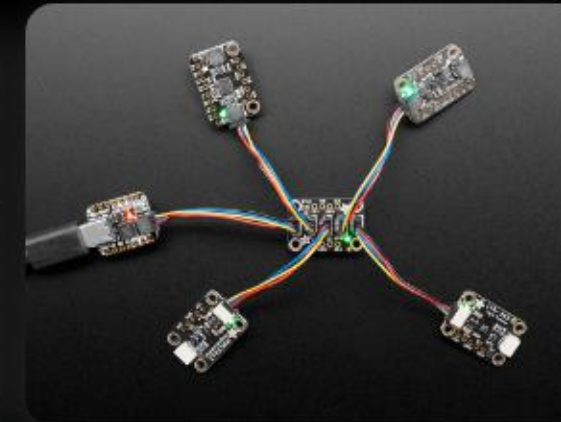
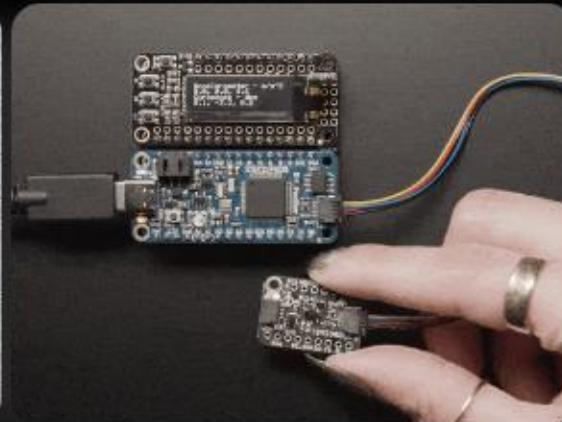
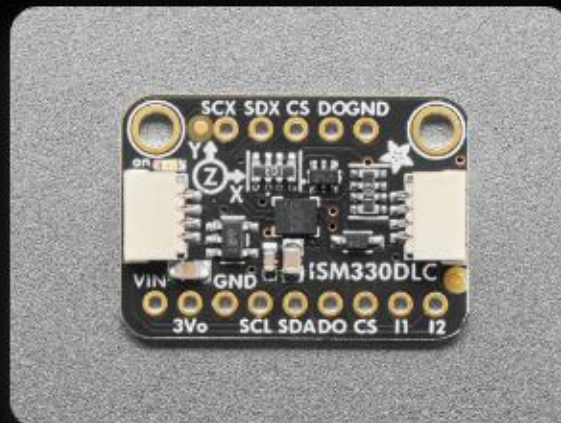


Vendors

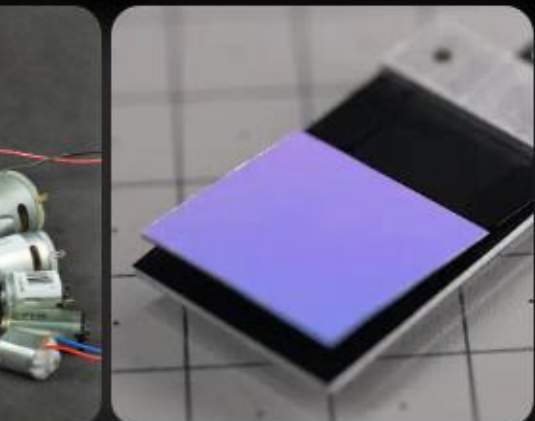
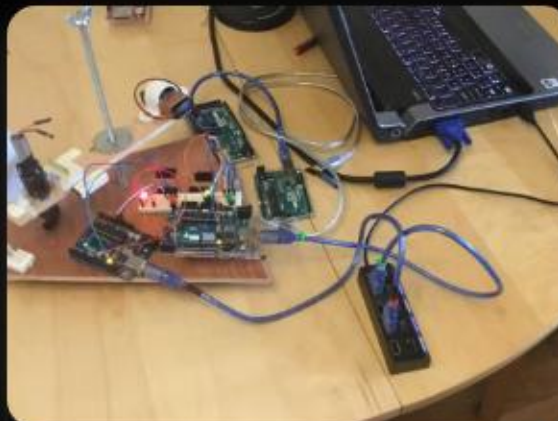
- Digikey
- Mouser

and Modules

Evaluation Board



Power



Actuator

Vendors

- Digikey
- Mouser

Laws

✓ What We Care About

$$V = I \times R$$

Ohm's Law

$$P = V \times I$$

Power Law

KVL & KCL

Kirchhoff's Laws

Simple & Practical

✗ What We Won't Touch

Maxwell's Equations

Electromagnetic Theory

Quantum Mechanics

Fundamental Physics

Solid State Physics

Semiconductor Theory

Complex & Theoretical

Focus on what matters for prototyping

MCU

"Arduino" or "microcontroller" = MCU Chip + Development Board + Peripherals



MCU Chips

ARM Cortex-M

- ✓ Industry standard
- ✓ Excellent tools
- ✓ Wide ecosystem
- ✗ Complex setup
- ✗ Higher cost

ESP32/ESP8266

- ✓ Built-in Wi-Fi/BT
- ✓ Low cost
- ✓ Easy to use
- ✗ Power hungry
- ✗ Limited I/O

RISC-V

- ✓ Open source
- ✓ Future-proof
- ✓ Customizable
- ✗ Limited tools
- ✗ Smaller ecosystem

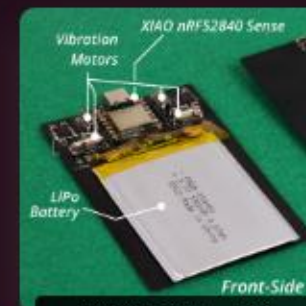
AVR

- ✓ Simple & reliable
- ✓ Arduino compatible
- ✓ Low power
- ✗ Limited performance
- ✗ 8-bit architecture

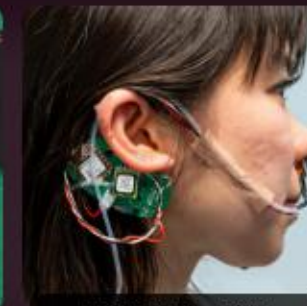
Development Boards

Seeed Studio Xiao

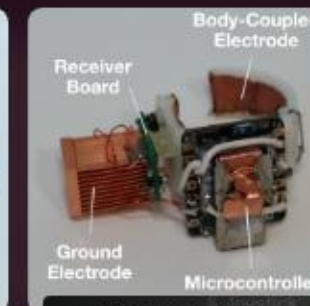
- Xiǎo 小, small!
- Researcher's favorite



Retnanto et al., 2024



Brooks et al., 2024



Kong et al., 2024

ESP32 DevKits
(various vendors)

STM32 Nucleo/Discovery
(STMicroelectronics)

Fabrication

Easy

1. Connectors

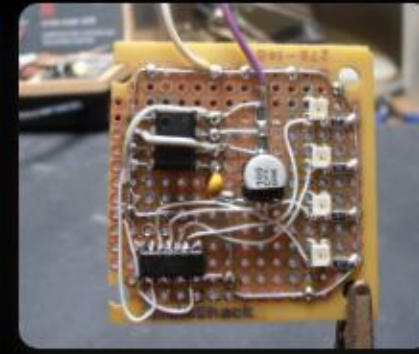
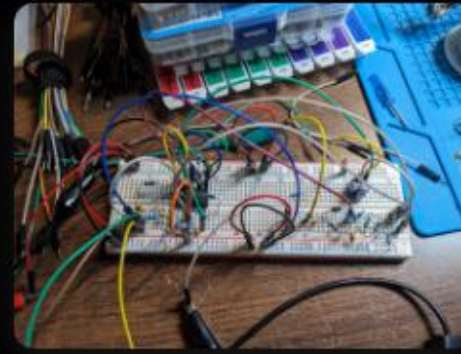
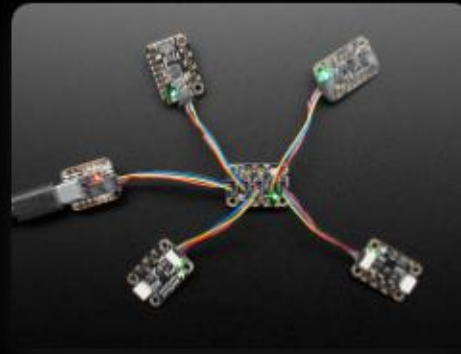
Plug-and-play modules with standard connectors. No soldering required. Perfect for quick concept validation and system testing.

2. Breadboards

Solderless prototyping with jumper wires. Rapid iteration and circuit testing. Great for learning and experimenting.

3. Proto & Perf Boards

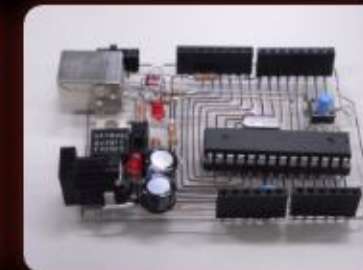
Perforated boards for permanent prototypes. Proto boards have some traces, perf boards are blank. Requires soldering skills.



Hard

4. ?????

Something cool and mysterious... 🔥



Manufacturing

PCB Design Fundamentals

Layer stackup planning

Trace width calculations

Via placement strategies

Component placement rules

Signal Integrity

Impedance control

Crosstalk minimization

Ground plane design

High-speed routing

Manufacturing Considerations

DFM (Design for Manufacturing)

Assembly constraints

Testing strategies

Cost optimization

From prototype to production-ready PCB

Software

Arduino IDE

Beginner-friendly IDE with built-in libraries and examples. Perfect for learning and quick prototyping with Arduino boards.

[Arduino IDE Image]

PlatformIO

Professional multi-platform IDE with VS Code integration. Supports hundreds of boards and advanced debugging features.

[PlatformIO Image]

Keil

Industry-standard ARM development environment. Professional debugging tools and code optimization features.

[Keil Image]

Chip-Specific

STM32CubeIDE - Official STM32 development
ESP-IDF - ESP32 native framework

MicroPython / CircuitPython

Python for microcontrollers with interactive REPL.
Great for rapid prototyping and education.

Protocol

Serial Protocols

UART/USART - Simple point-to-point

SPI - High-speed synchronous

I2C - Multi-device bus

1-Wire - Single wire communication


High-Speed Protocols

USB - Universal connectivity


Ethernet - Wired networking

PCIe - High bandwidth

SATA - Storage interface

 Choose based on: Distance, speed, power, complexity

 Consider: Voltage levels, timing requirements, error handling

 Debug tools: Logic analyzers, protocol decoders, oscilloscopes

Networking

Local Networks

Wi-Fi Direct - Device-to-device

Bluetooth Mesh - Self-healing mesh

Zigbee - Low power mesh

Thread - IPv6 mesh for IoT

Wide Area Networks

LoRaWAN - Long range, low power

Cellular (LTE-M, NB-IoT) - Global coverage

Satellite - Remote locations

Sigfox - Ultra-low power WAN


Network Topologies


Star - Central hub model


Mesh - Self-organizing network


Tree - Hierarchical structure

Ring - Redundant connections

 Range considerations: Indoor vs outdoor, obstacles, interference

 Power trade-offs: Transmission power vs battery life

 Cost factors: Infrastructure, licensing, module prices

 Security: Encryption, authentication, network isolation

Part 2

Inputs and Outputs

and the cybernetic systems we rely on

Actuator

Output devices that convert electrical signals into physical actions

- Motors
- Electromagnets
- Servo Motor
- Linear Motor
- Pneumatic actuators
- Hydraulic systems
- Thermal actuators
- Piezoelectric actuators
- Shape-changing material

Actuator

Electromagnetic Actuators

move and actuate

Motors

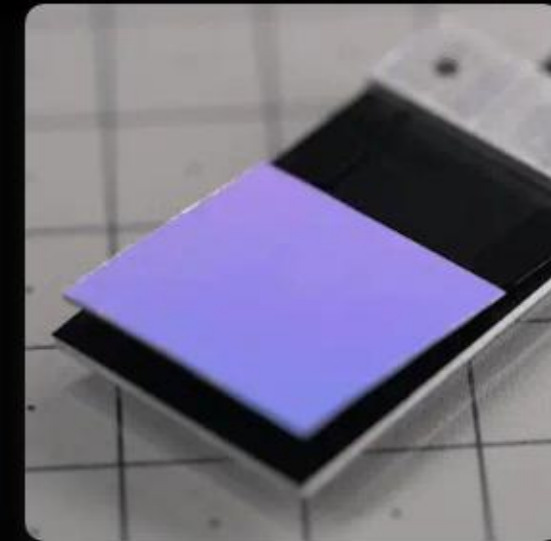
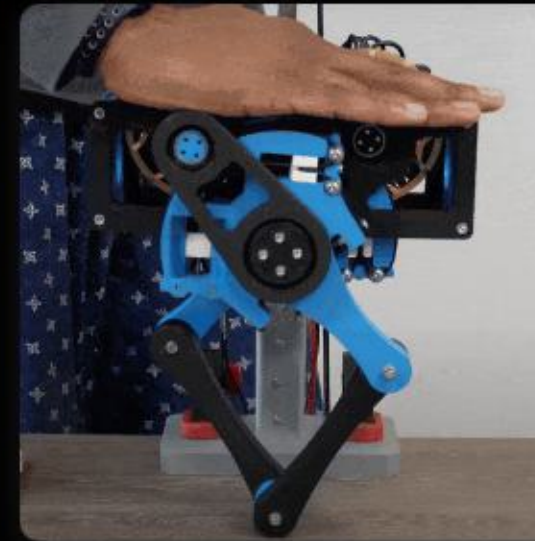
- AC motors
- Brushed DC motors
- BLDC motors
- Linear motors

Electromagnets

- Push/Pull Solenoids
- Relay Coils
- * PCB magnets

Servo Motor

A servo motor is not just a motor, but a complete system that combines a motor with an encoder to provide feedback for precise position control.



Actuator

Photo-Actuators

show and display

- LED Arrays
- LCD Screens
- OLED Displays
- E-Paper Displays



Sensor

Input devices that convert physical phenomena into electrical signals

- Environmental
- Thin-Film
- MEMS
- Biometric
- LiDAR sensors
- Ultrasonic sensors
- Hall effect sensors
- Capacitive touch sensors

Sensor

Analog Sensors

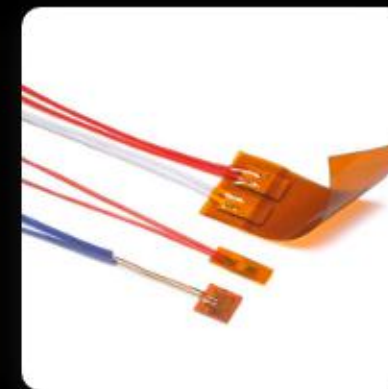
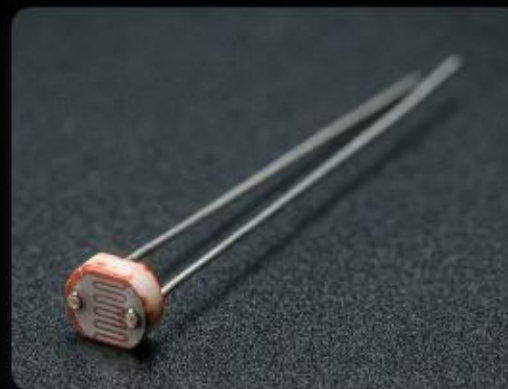
basically family of weird resistors

Environmental

- Thermistor
- Photocell
- Chemresistor
- Gas Sensors

Thin-Film

- FSR (Force)
- Strain Gauge
- Soft Potentiometer
- Soft Piezo
- *and more*

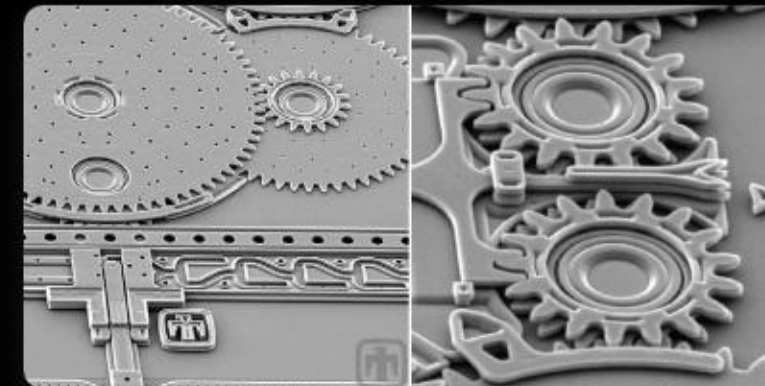
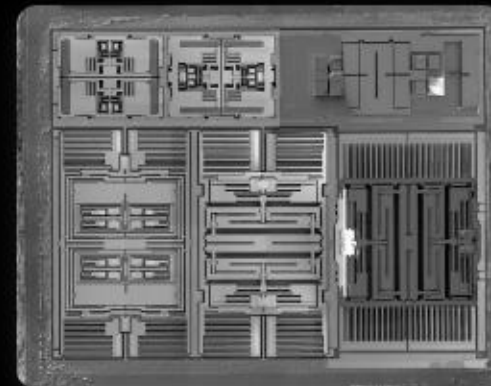
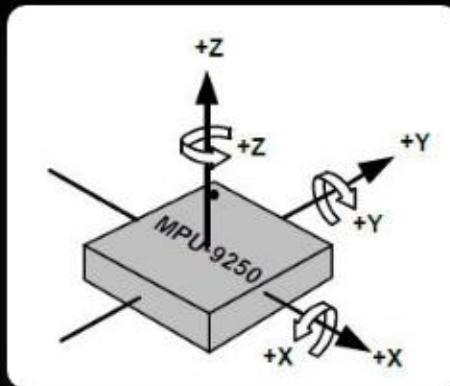


Sensor

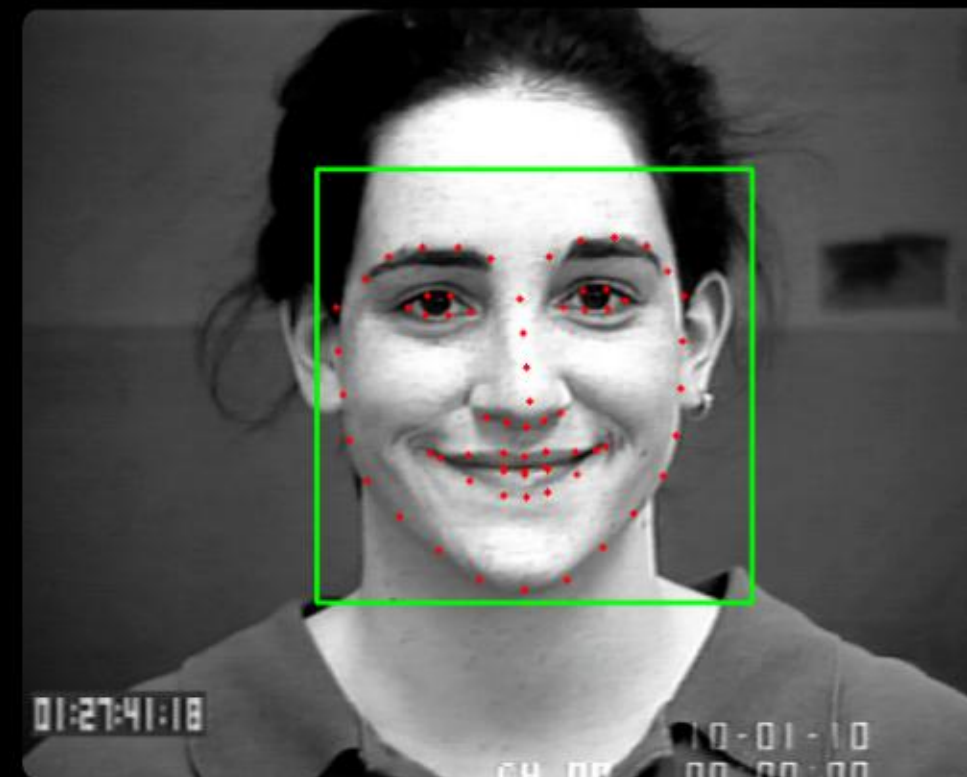
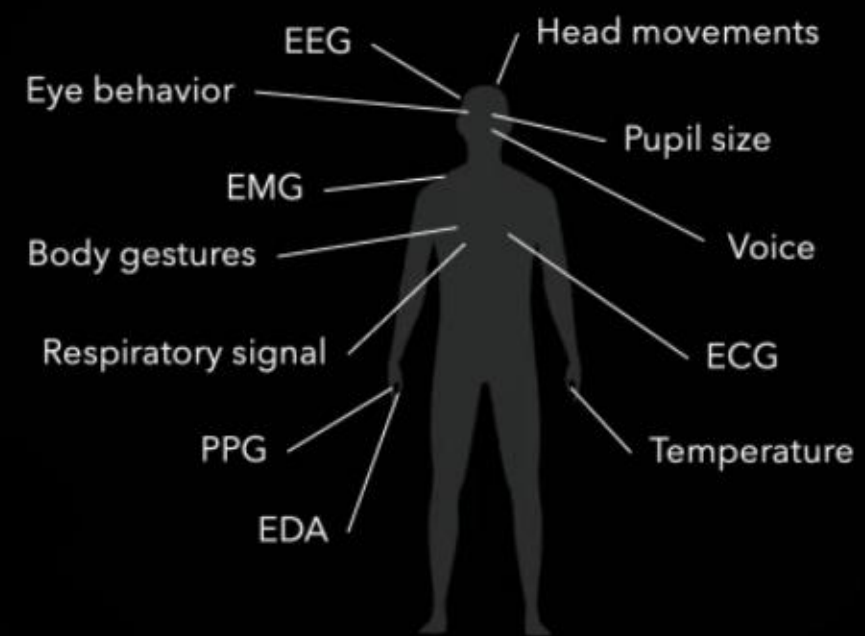
MEMS Sensors

Micro-Electro-Mechanical Systems

- IMU (Inertia Measuring Unit)
- Magnetometers
- Pressure
- Microphone
- Barometric
- and many more



Biometric



Biometric

Biometric Sensors

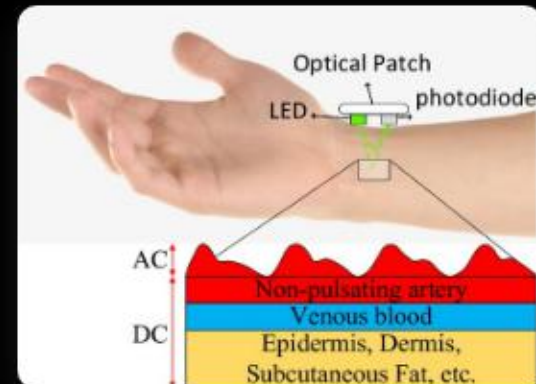
identity verification and health monitoring

Bio-electric

- GSR (Galvanic Skin Response)
- PPG (Photoplethysmogram)
- EMG (Electromyography)
- EEG (Electroencephalography)

Identity & Access

- Camera (Facial recognition)
- Microphone (Voiceprint Recognition)



Part 3

Get ready for the Workshop

Your Kit

[Placeholder: Kit image]

Workshop kit overview and contents

Your Kit

[Placeholder: Kit form/details]

Detailed kit specifications and usage instructions

Warm-up

[Placeholder: Warm-up exercise image]

Initial hardware exercise (15 minutes)

Warm-up

[Placeholder: Warm-up exercise form/details]

Step-by-step instructions and requirements

Hard Mode

[Placeholder: Hard Mode challenge image]

Advanced challenge covering multiple topics (45 minutes)

Hard Mode

[Placeholder: Hard Mode challenge form/details]
Comprehensive project requirements and guidelines

System Diagram

[Placeholder: System diagram image]

Hardware-web system and signal flow

System Diagram

[Placeholder: System diagram form/details]

Technical specifications and implementation details