MITMECHE

Idea Realization with Arduino and Rapid Prototyping

Fangzhou Xia

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MIT Splash Workshop

Department of Mechanical Engineering
Massachusetts Institute of Technology

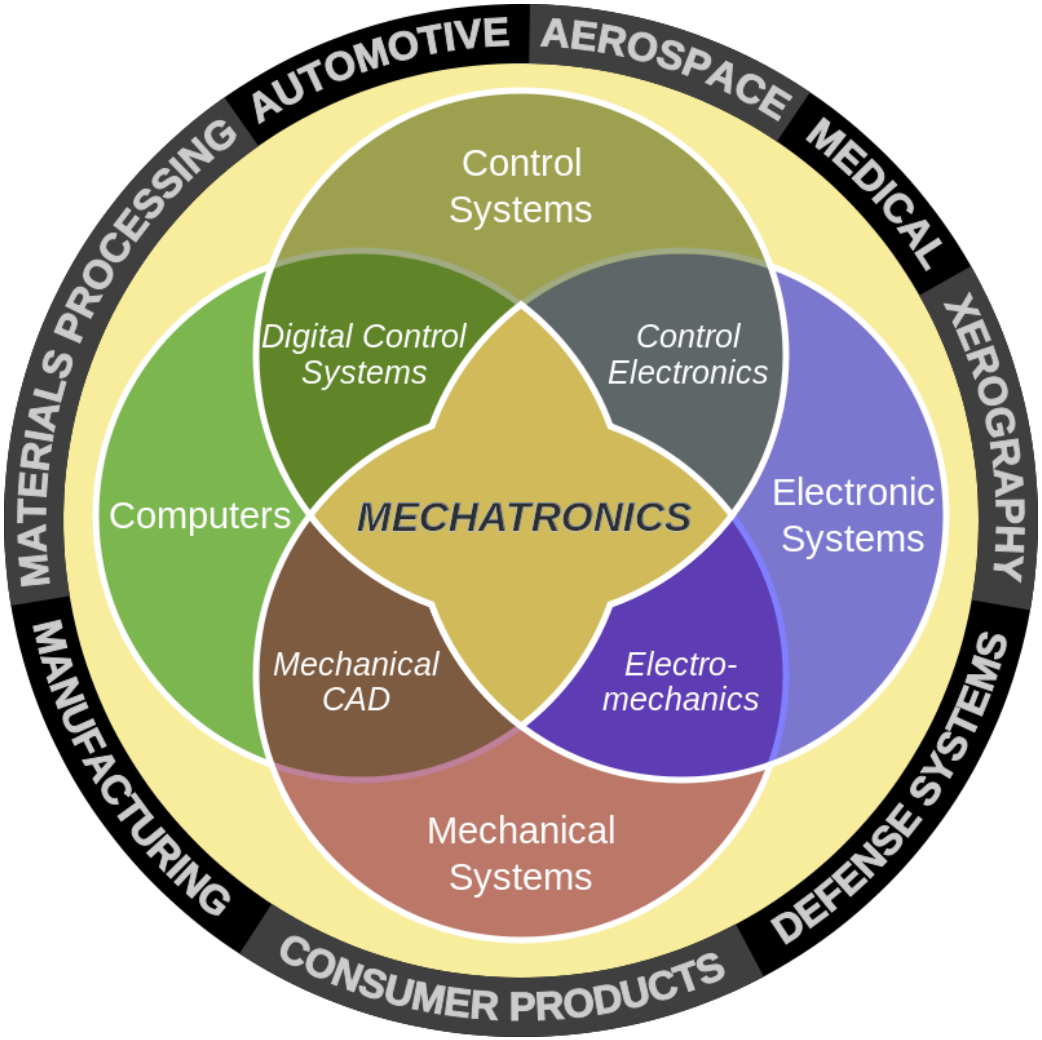
Outline

- Overview of Mechatronic Systems
- Project Examples
- Rapid Prototyping
  - Mechanical design
  - Fabrication tools
  - Electronics
  - Control and programming
- Additional Resources

About the Instructor

- Dr. Fangzhou Xia
- Degree at MIT Mechanical Engineering
  - Specialization in control, robotics and instrumentation
  - Minor in computer science
- Postdoc at Mechatronics Research Lab
  - Research: Atomic Force Microscope
- Dual B.S. in ECE and ME
- 2 time TA of 2.12 intro to robotics
- Teaching Interest
  - Mechatronic system
  - Precision instrumentation
  - Robot design and control

What is Mechatronics?



Mechatronic system illustration [ref]

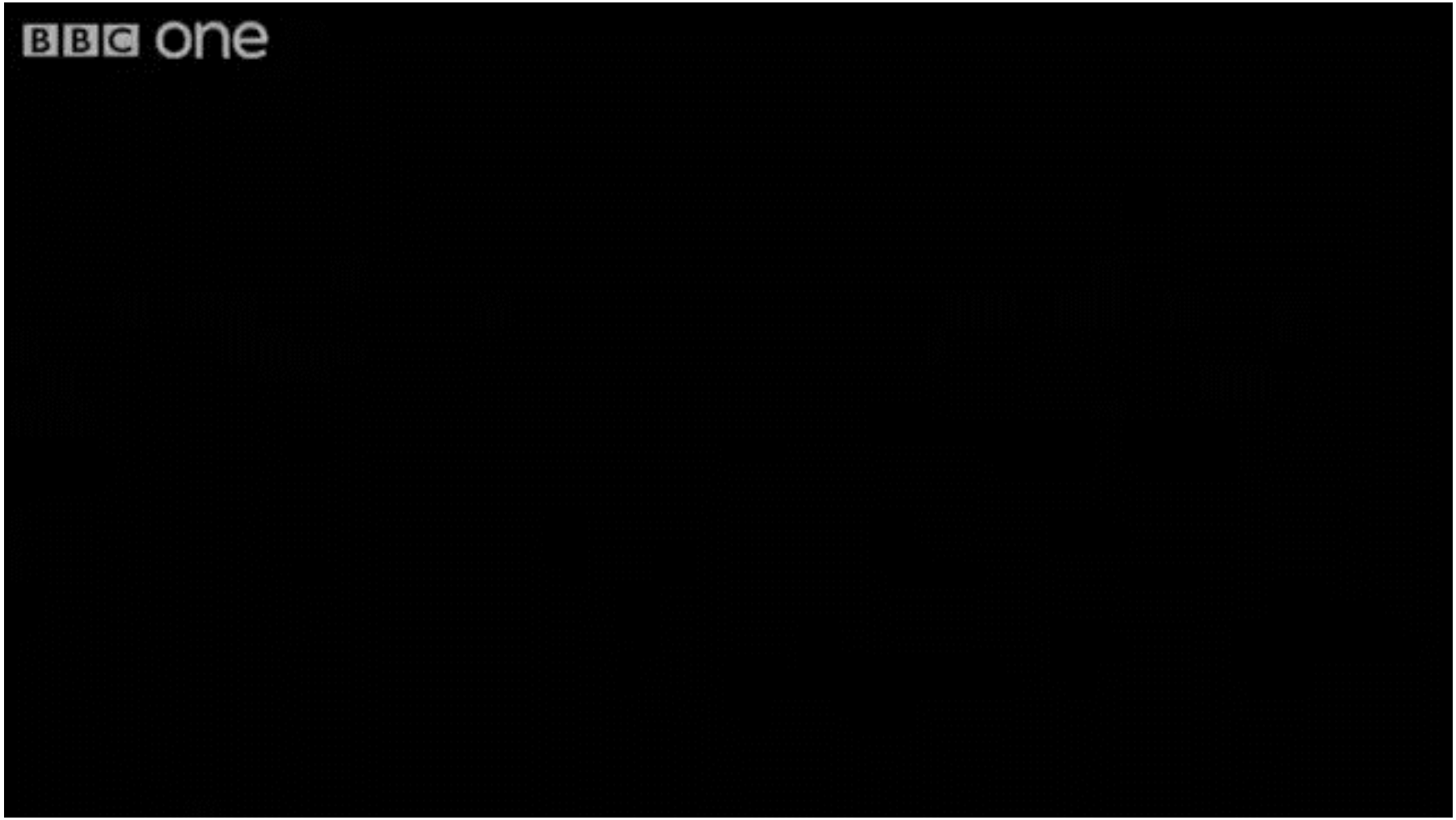
Mechanical Systems

- Mechanism design
- Mechanics for solids and fluids
- Thermal dynamics & heat transfer

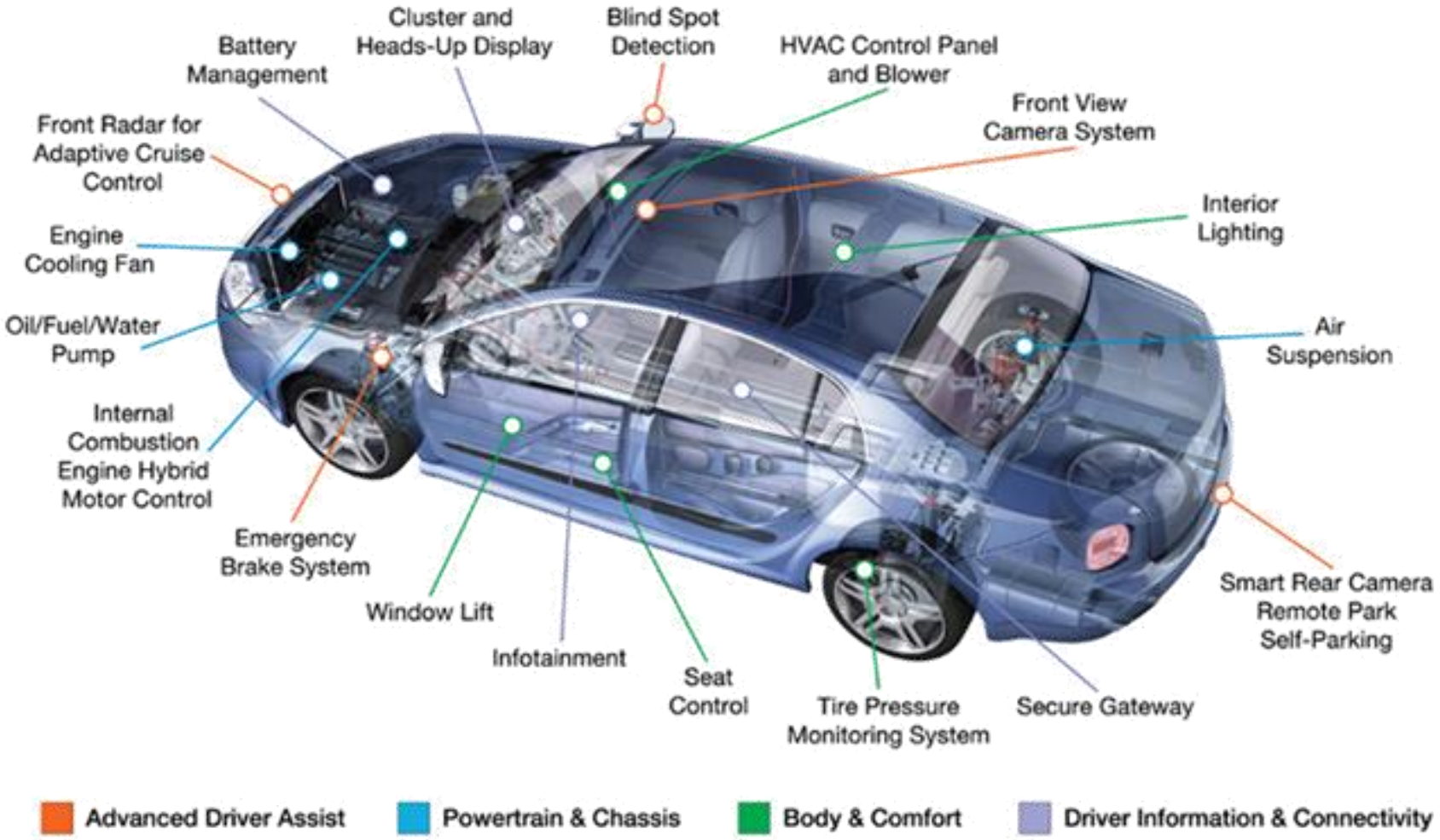
Mechatronic system illustration [ref]

Fluid and thermal systems

Jansen's Linkage



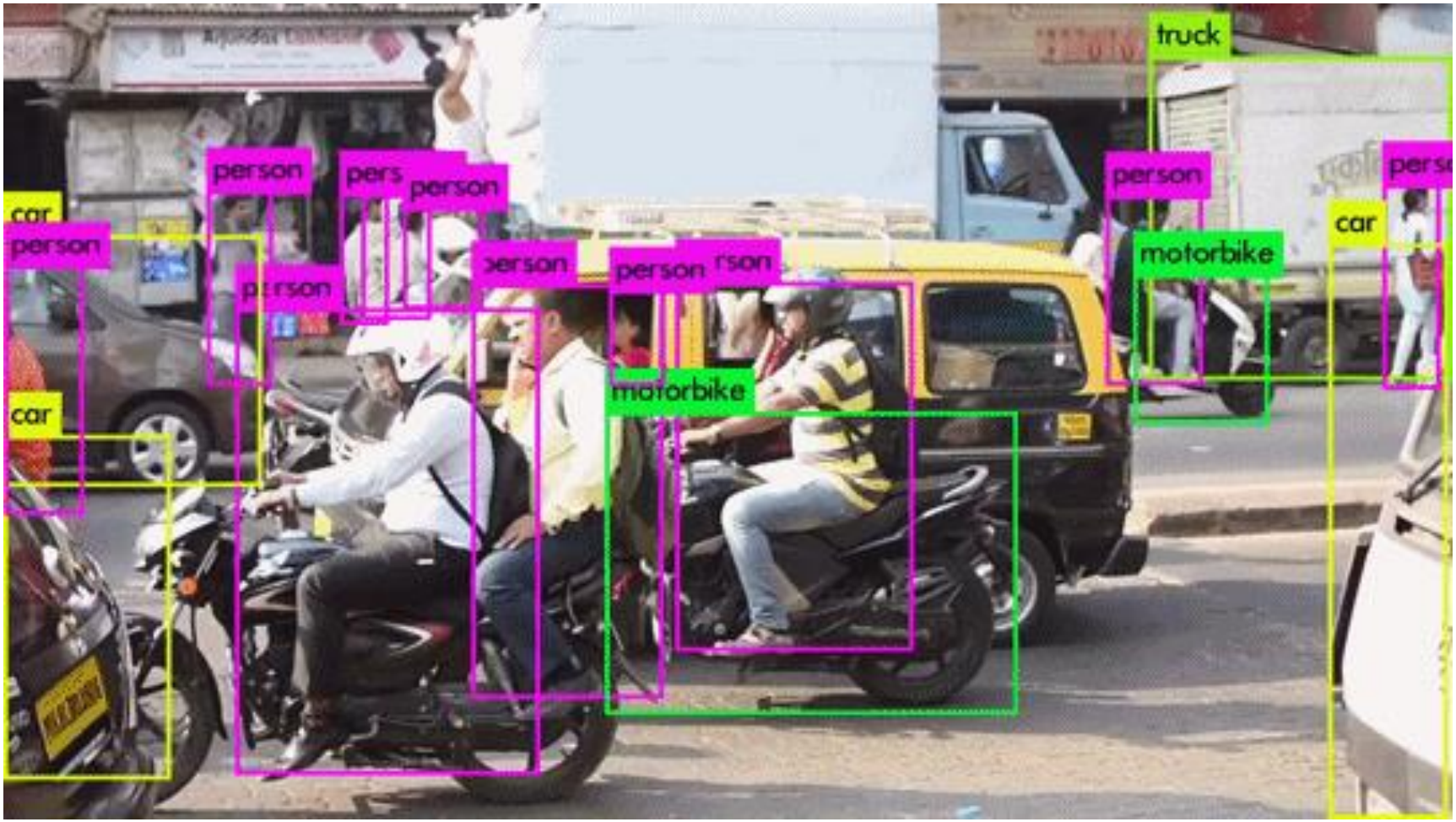
Electronic Systems Embedded in a Car



Embedded systems in car [ref]

Control Systems: Cubli Balance

Computer: Vision System



Background Requirement

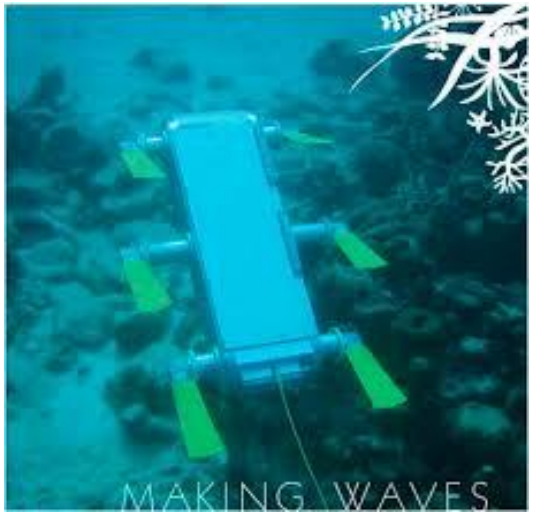
- Math background: calculus, differential equation (18.01/02/03)
- Electronics: circuit analysis, signals and systems, programing (6.001/002/003)
- Mechanical: design and manufacturing (2.00/007), system control (2.003/004)
- Related classes: introduction to robotics (2.12), instrumentation (2.671)
- Don’t panic, we can start simple to familiarize ourselves with some tools
- Let’s do a quick survey first

MIT Hacks fire hose of knowledge [ref]

What we mean by drinking from a fire hose [ref]

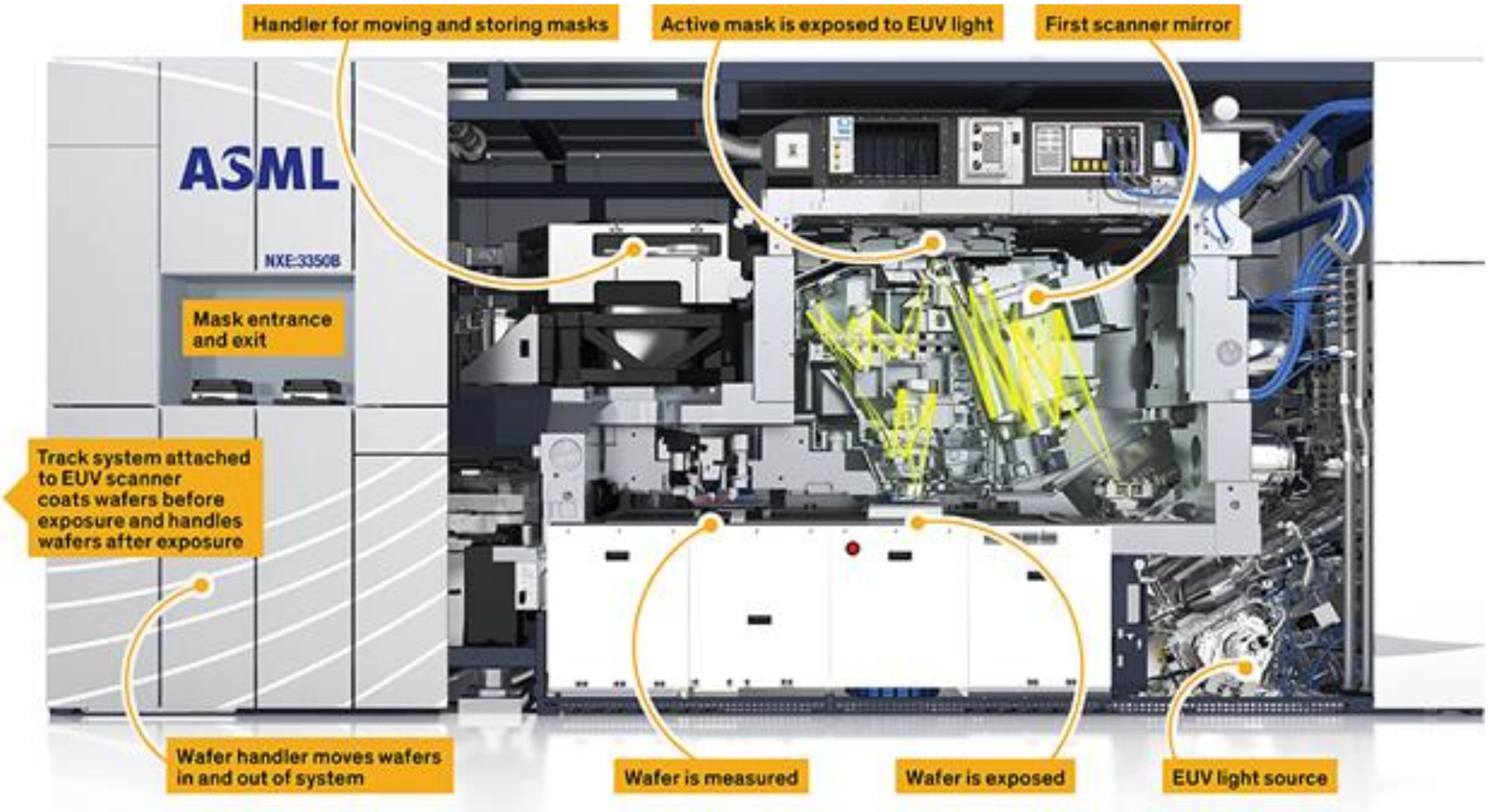
Project Examples

Robotics Applications



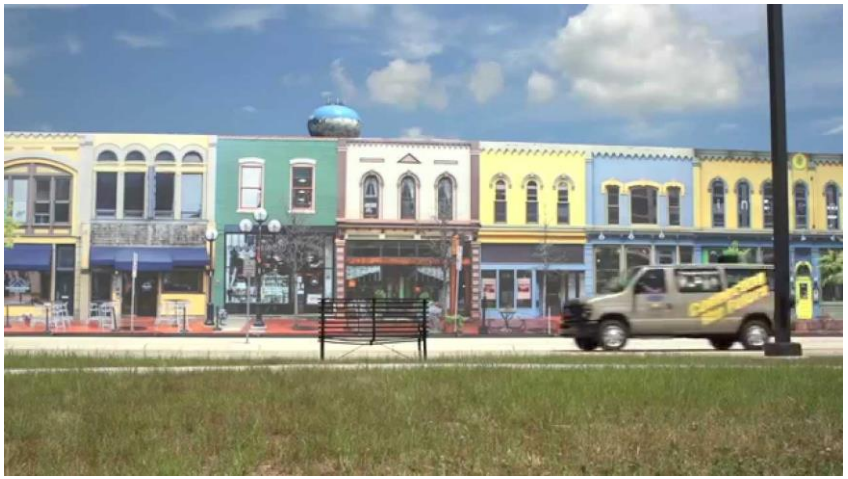
Instructable page for project ideas [ref]

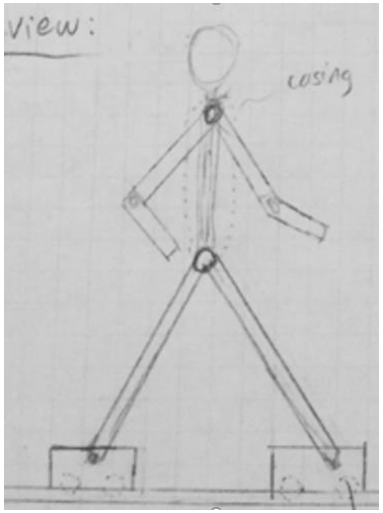
Mechatronics Applications

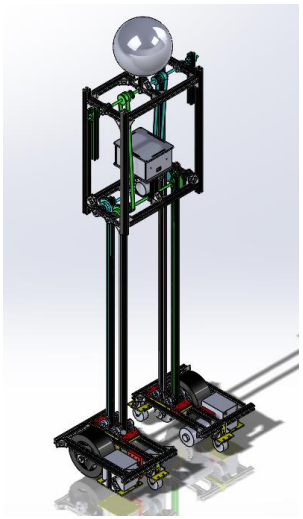


Instructable page for project ideas [ref]

Case Study: Mechanized Pedestrian

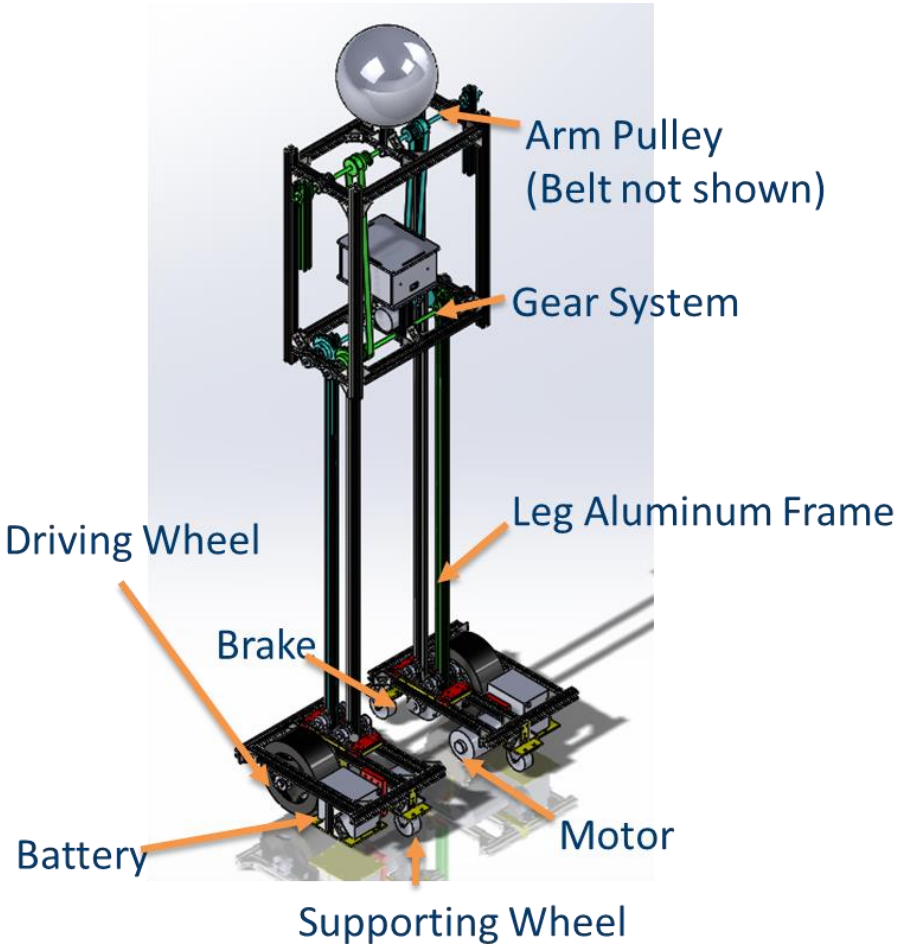


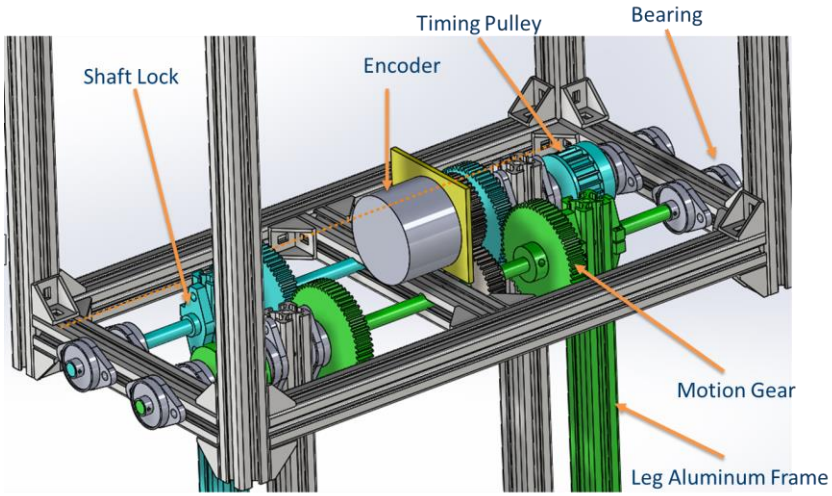


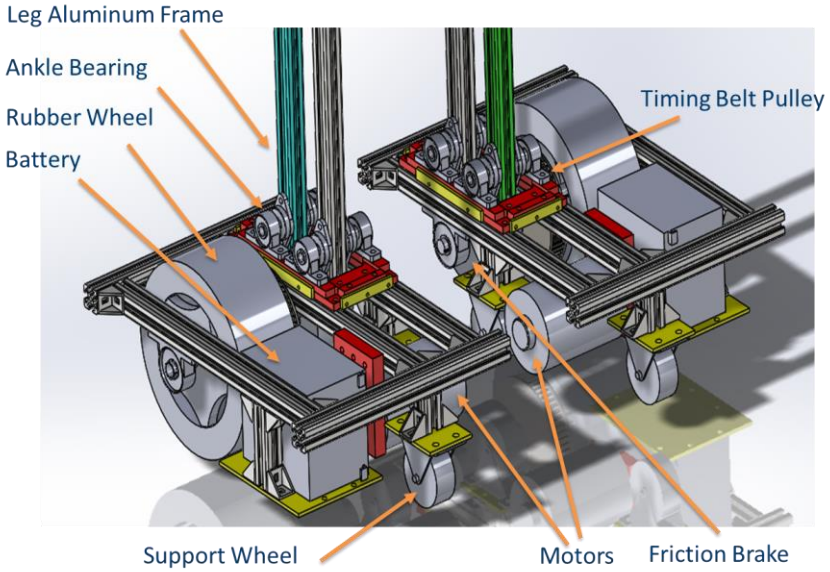


Case Study: Mechanized Pedestrian

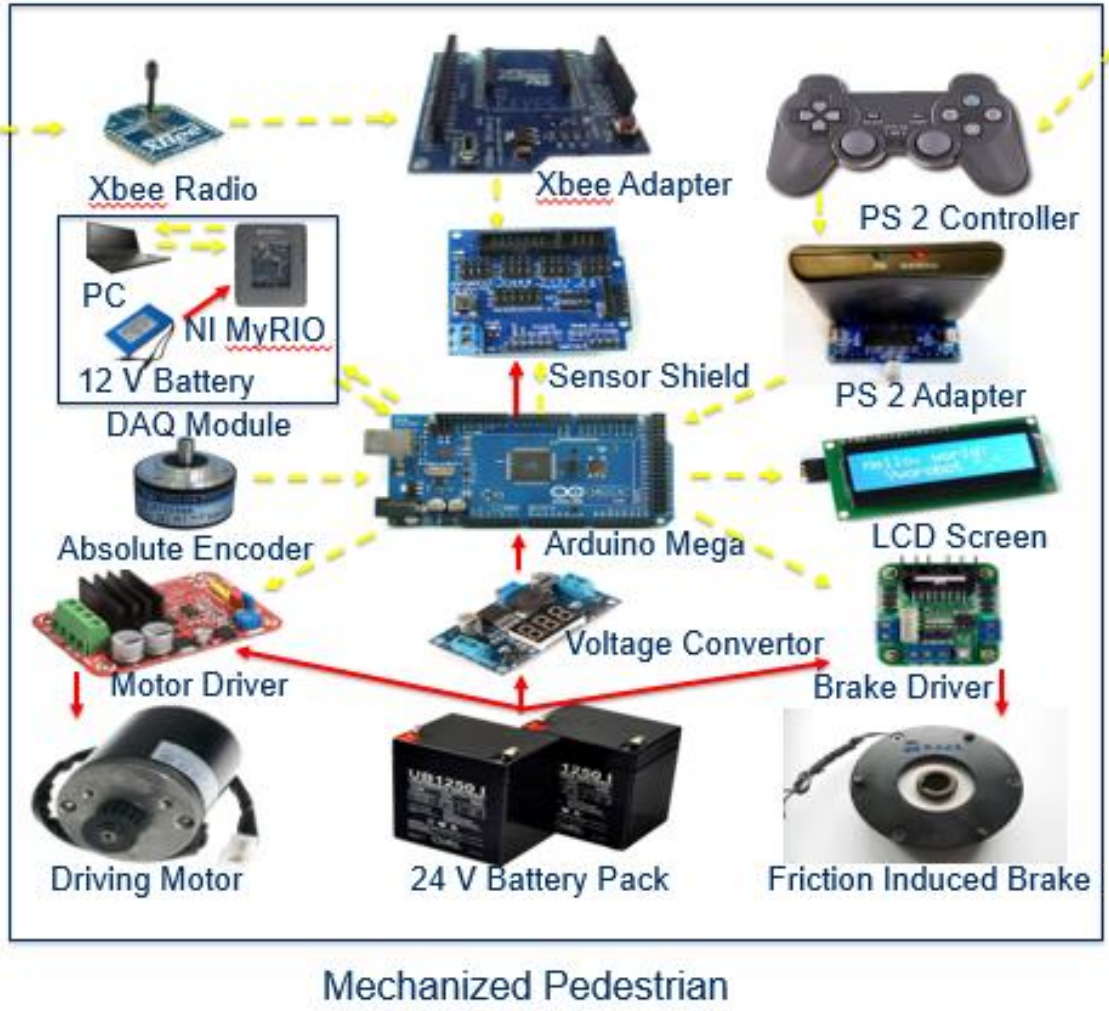
Mechanical Systems







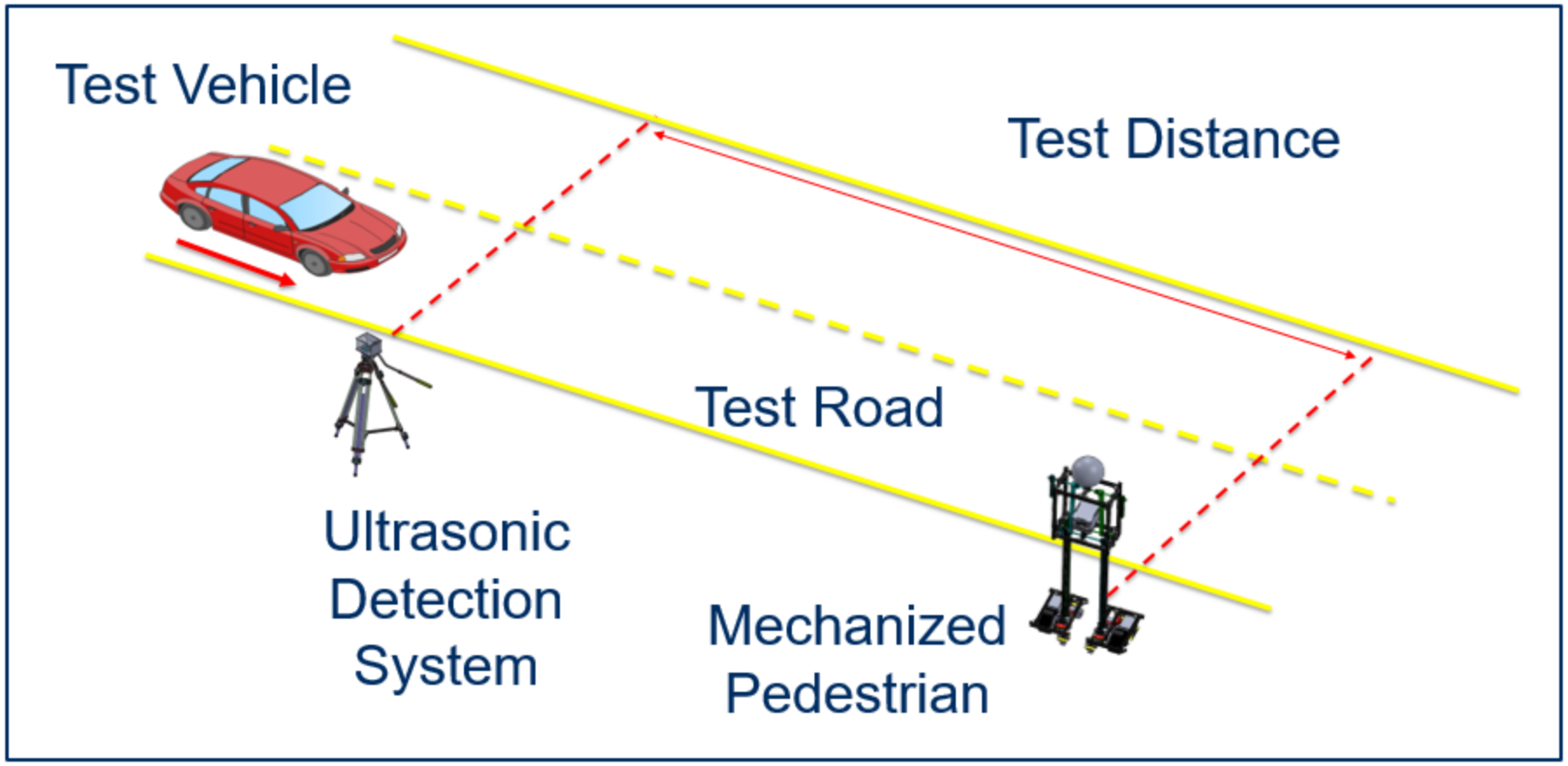
Electrical Systems



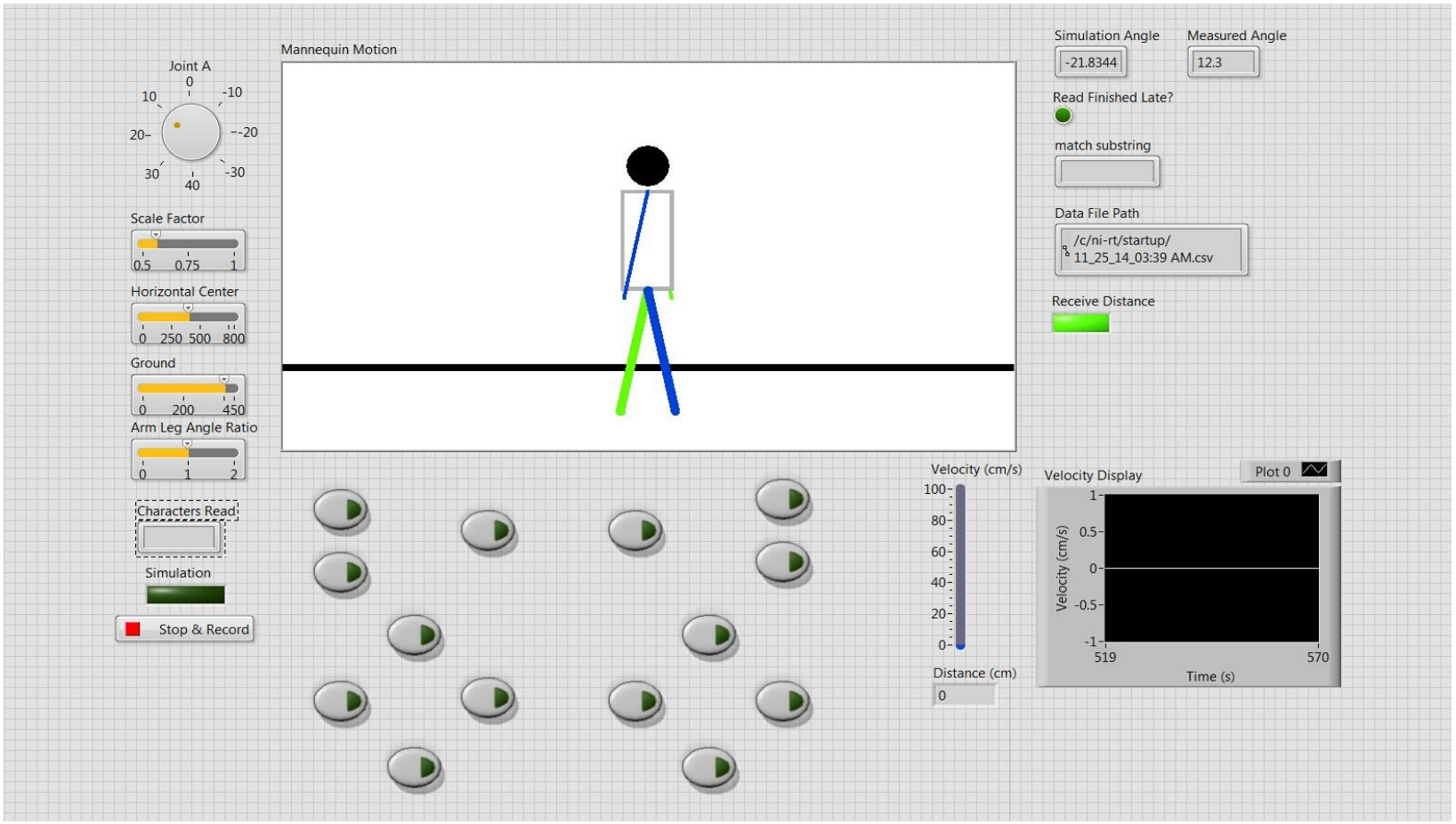
Signal Flow

Energy Flow

Control Systems



Computer User Interface



Mechanical Design

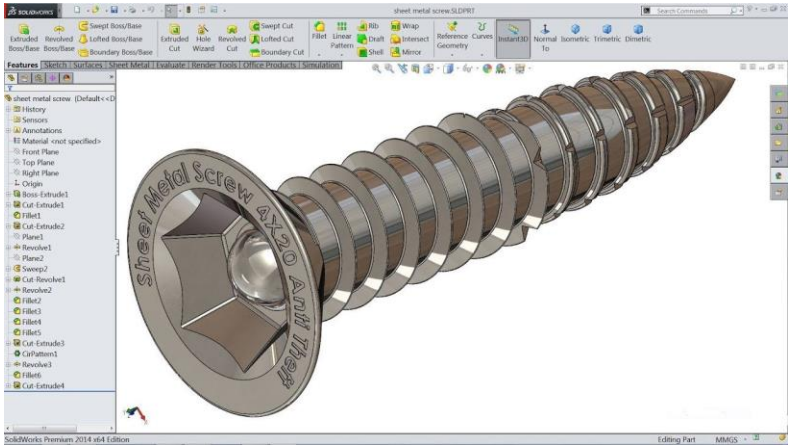
Computer Aided Software

- Purpose of CAD/CAM/CAE
  - Computer Aided Design software helps designers to manage complex design
  - Computer Aided Manufacturing (CAM) automates manufacturing process
  - Computer Aided Engineering includes simulation studies
- Mechanical CAD Software
  - **Solidworks/OnShape**, UG NX, Catia, Creo/ProE, AutoCAD Fusion 360, Google SketchUp, etc.

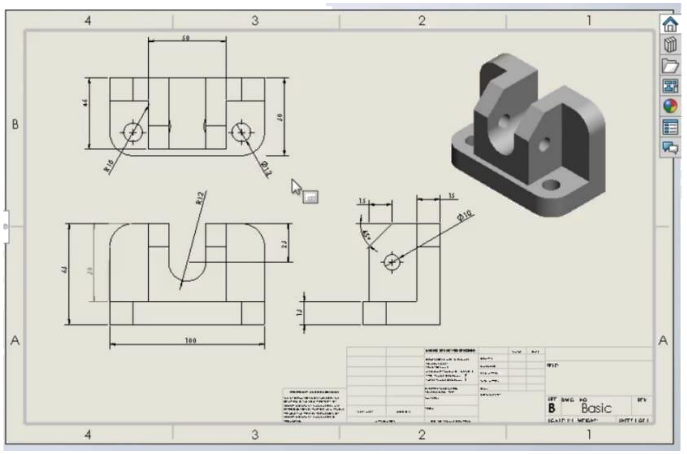
- Industrial Design CAD Software: Rhinoceros. Etc.
- Animation: 3ds Max, Maya, etc.

Solidworks Capabilities

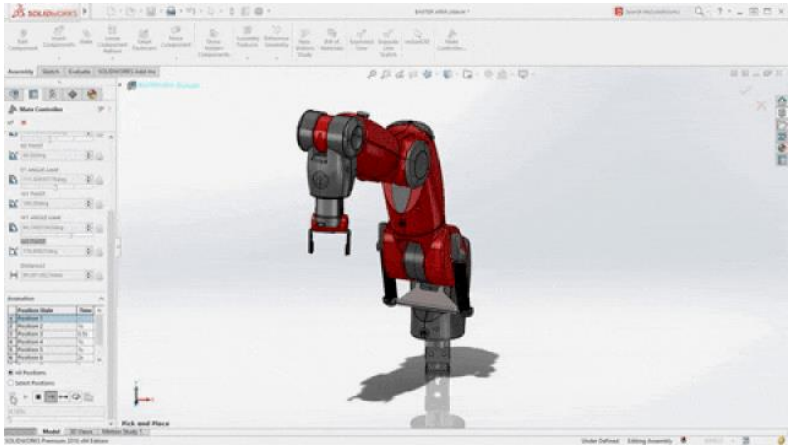
- Create parts, dimension drawings, motion studies, finite element analysis



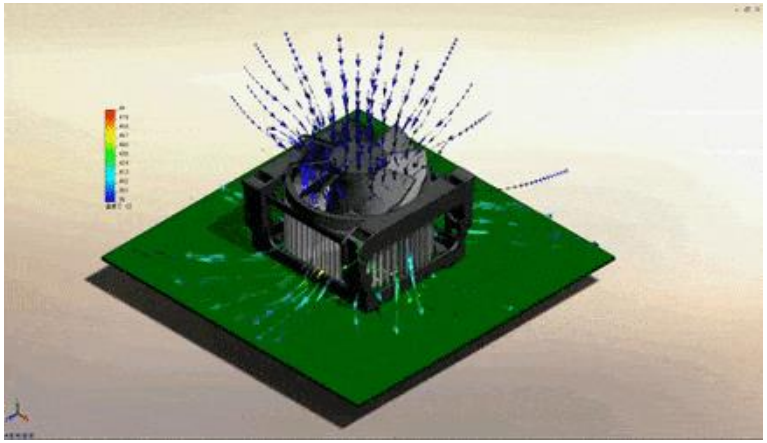
3D component



2D drawing



Assembly motion studies



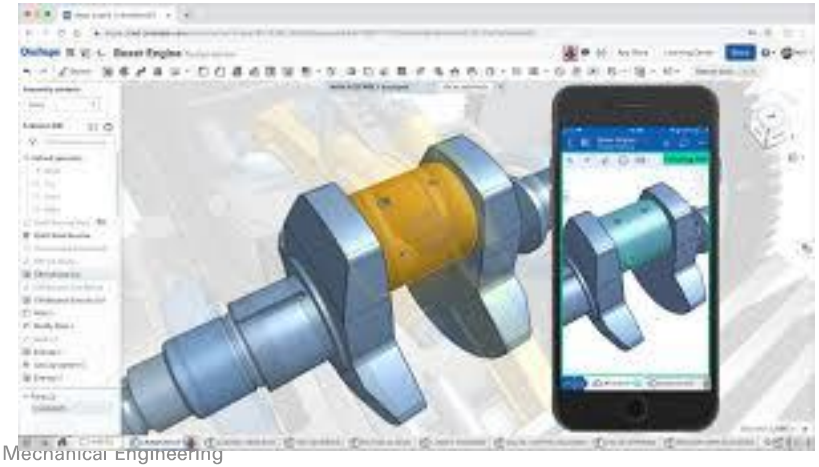
Flow analysis

Solidworks Rendered Assembly Animation

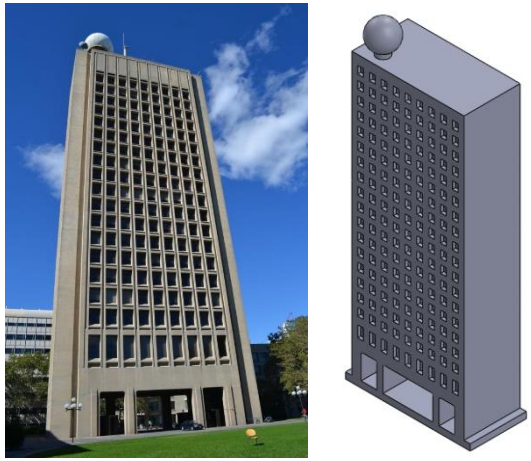
- Assembly of an Atomic Force Microscope Created using Solidworks

OnShape Exercise: 3D Modeling

- Activity time: 20 minutes
- Break time: 5 minutes
- Return time: 5:00 pm
- Register OnShape Account: https://www.onshape.com/en/products/free
- For CAD beginners: follow this video to start
  - https://youtu.be/pMWnsHpDlQE
- For experienced user: try model the simplified MIT green building (Fancy Demo)
  - Model as a single part with 1:1000 scaling (1m becomes 1 mm)
  - Data available on Wikipedia: https://en.wikipedia.org/wiki/Green_Building_(MIT)



OnShape interface



MIT Green Building

MITMECHE

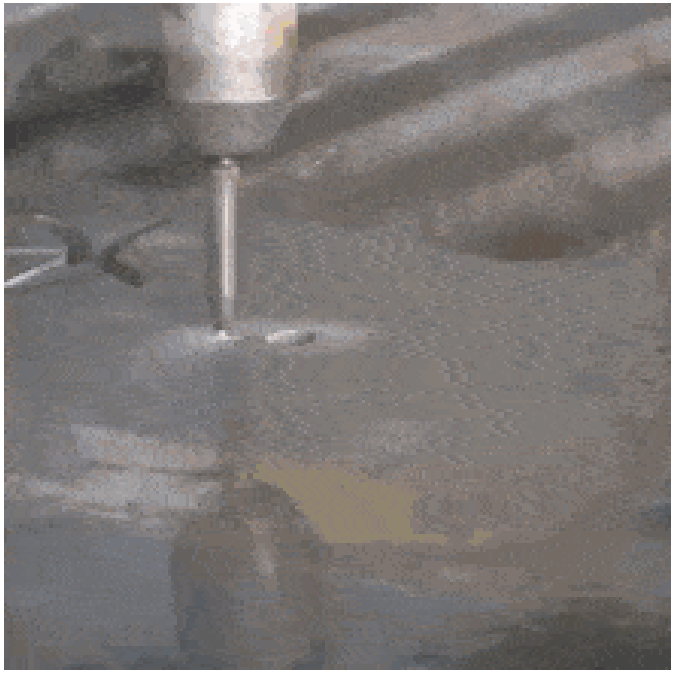
Fabrication Tools

Prototyping Facilities at MIT

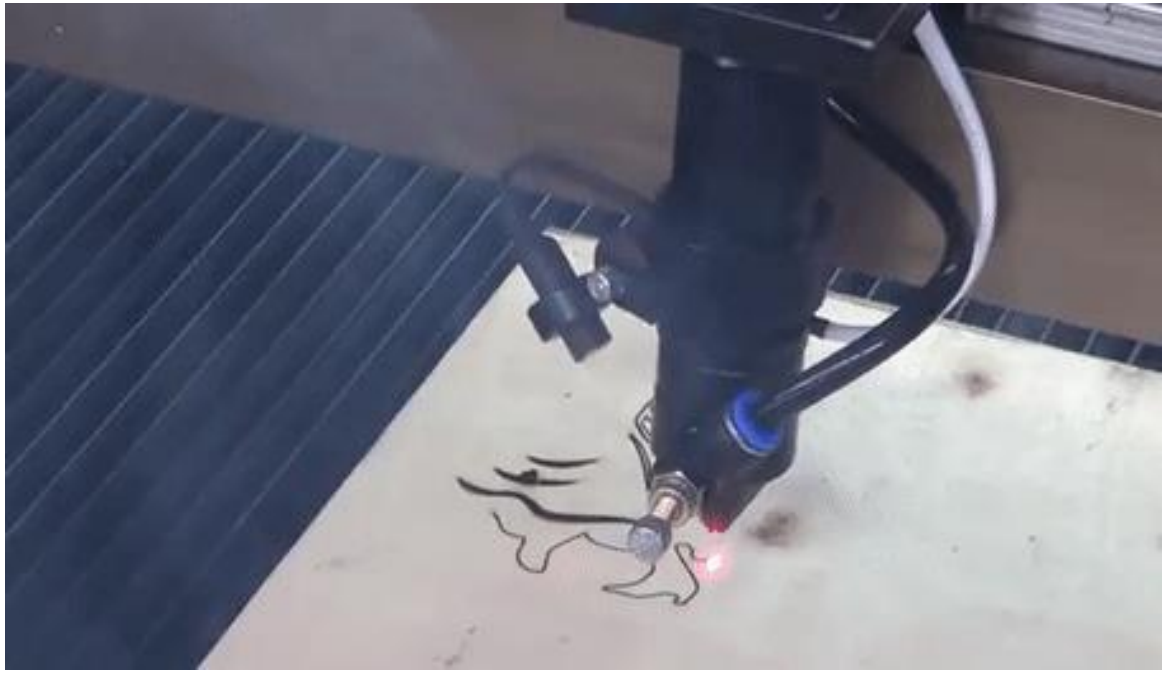
- MIT On-campus maker spaces
  - Mechanical Engineering Makerworks
- Tools available at the Makerworks
  - Laser cutting (acrylic, paper, wood)
  - Water jet (aluminum, steel)
  - CNC mill and lathe (aluminum, steel)
  - Bandsaw, drill press and hand tools
  - 3D printing
- Off-campus outsource fabrication option
  - Shapeway 3D printing
  - ProtoLabs CNC

2D Geometry Creation

- Water jet cutting
- Laser cutting



Water Jet



Laser cutting machine

Machining Tools

- Milling operation
- Turning with lathe
- Bandsaw

Mill

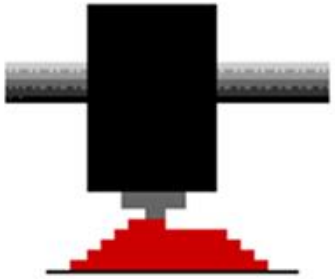
Lathe

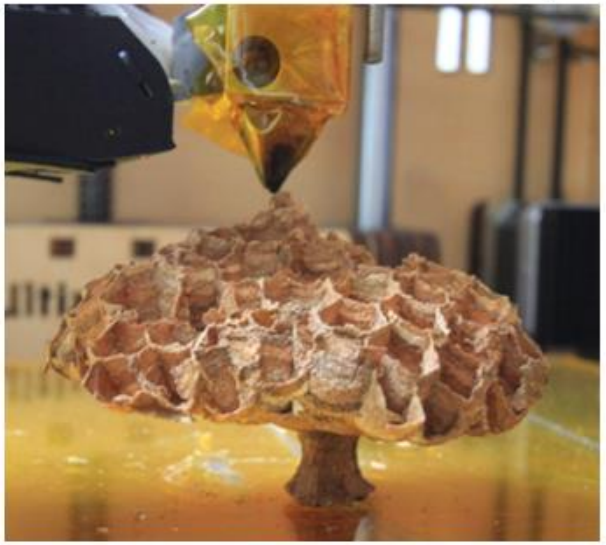
Bandsaw

Additive Versus Subtractive

Material subtraction (removal)
"top-down"

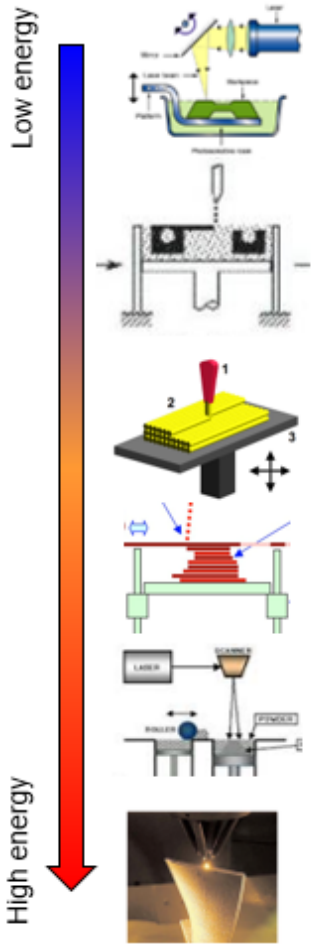
Material addition
"bottom-up"





Types of 3D Printing

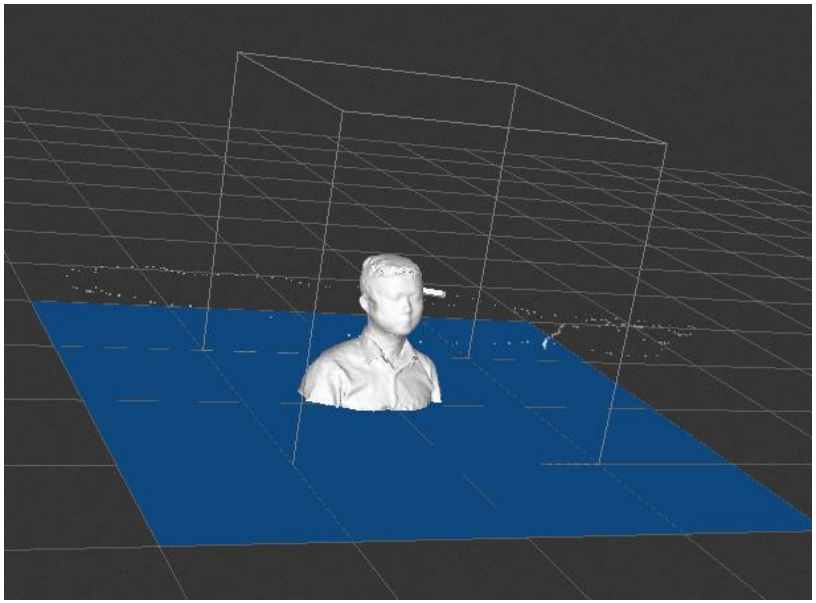
The 7 AM methods (from ASTM F42)



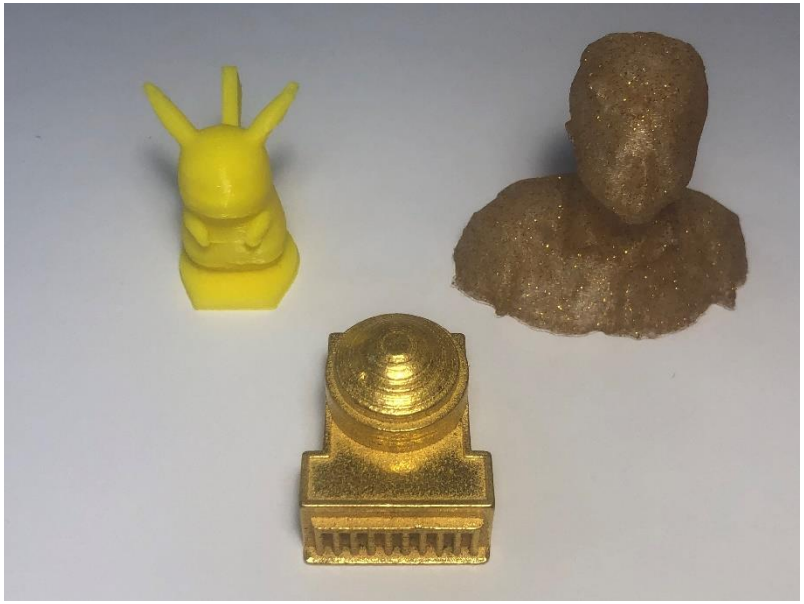
- **Vat photopolymerization** (→ SLA): material is cured by light-activated polymerization.
- Material jetting (→ Objet): droplets of build material are jetted to form an object.
- Binder jetting (→ 3DP): liquid bonding agent is jetted to join powder materials.
- **Material extrusion (→ FDM)**: material is selectively dispensed through a nozzle and solidifies.
- Sheet lamination (→ LOM): sheets are bonded to form an object.
- **Powder bed fusion (→ SLS/SLM)**: energy (typically a laser or electron beam) is used to selectively fuse regions of a powder bed.
- Directed energy deposition (→ LENS): focused thermal energy is used to fuse materials by melting as deposition occurs.

3D Scanning & Printing

BIBO 3D printer



3D scan with Skanect

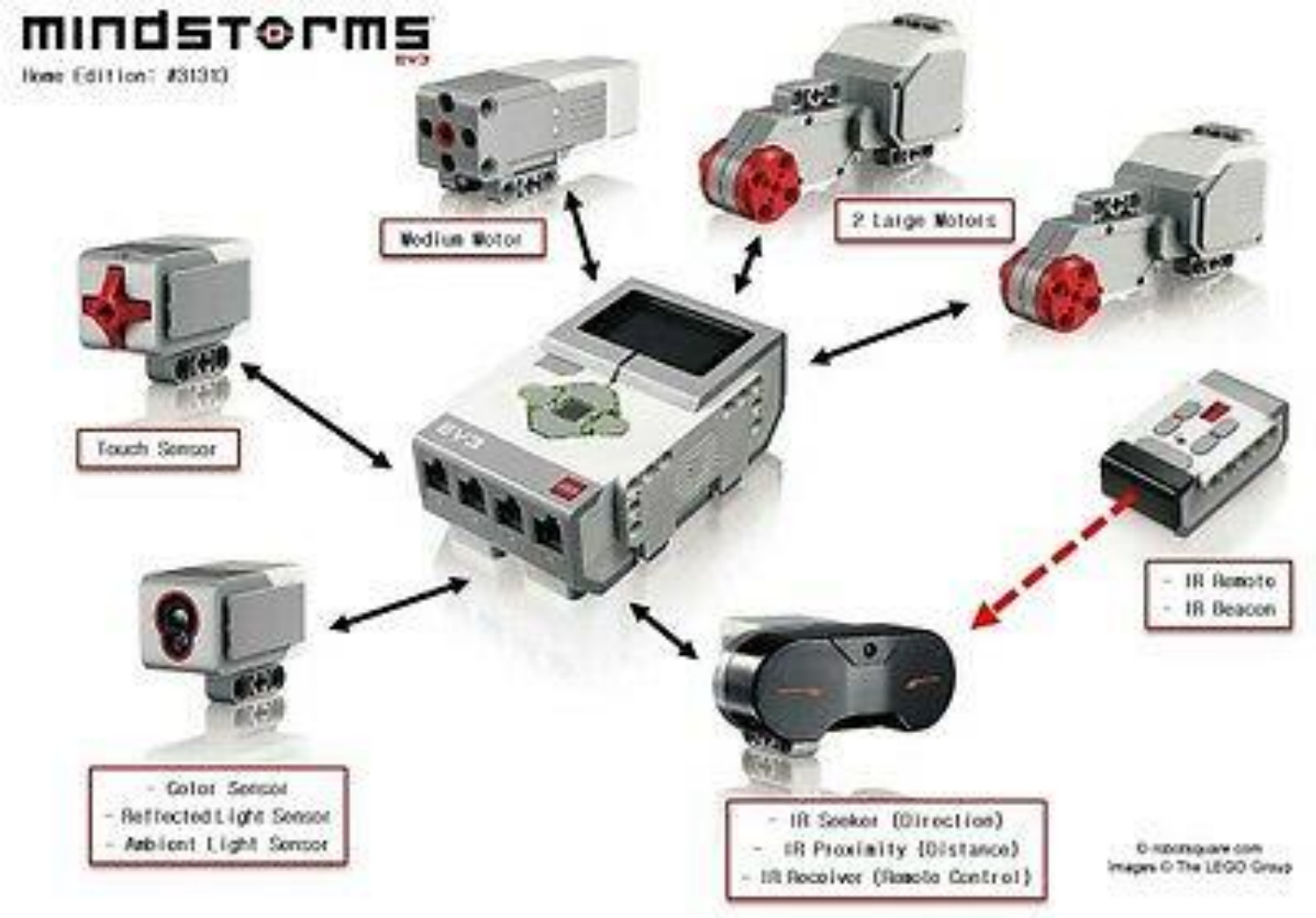


3D printed objects

Electronics

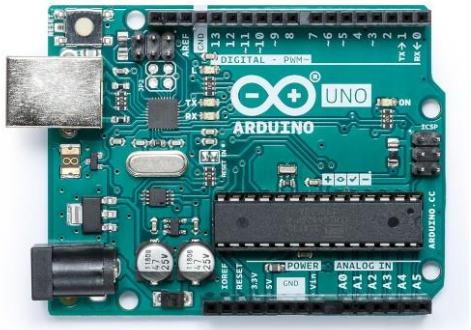
FIRST LEGO League

Mindstorm EV3 LEGO League

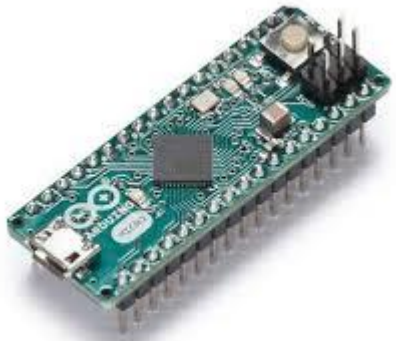


Arduino Microcontroller

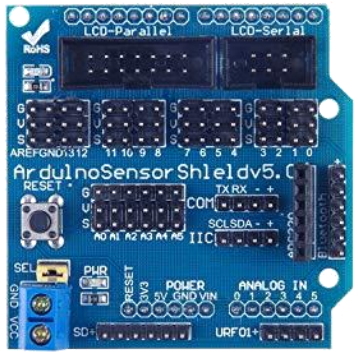
- Open source general purpose electronic prototyping platform
- Modular design with many extendable shields
- Suitable for data collection or controlling up to kHz range



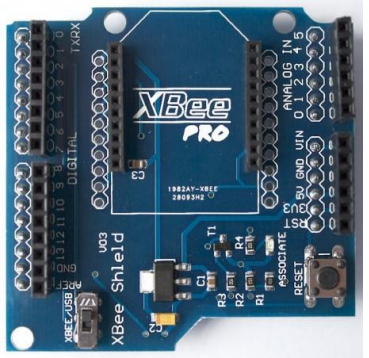
Arduino Uno [ref]



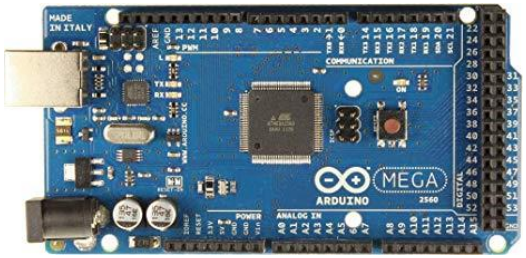
Arduino Micro [ref]



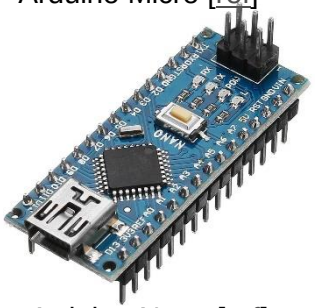
Arduino sensor shield V5 [ref]



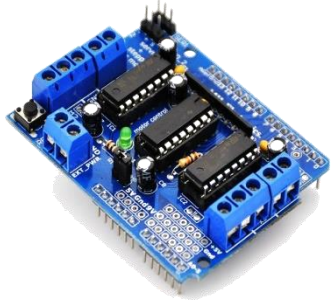
Arduino Bluetooth shield [ref]



Arduino Mega [ref]



Arduino Nano [ref]

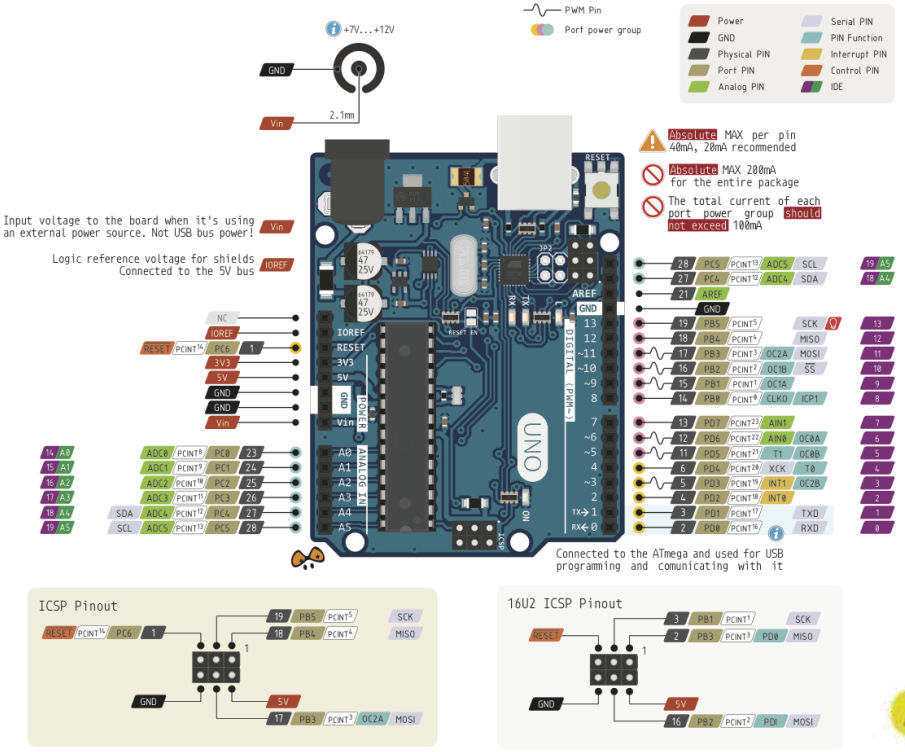


Arduino motor shield [ref]

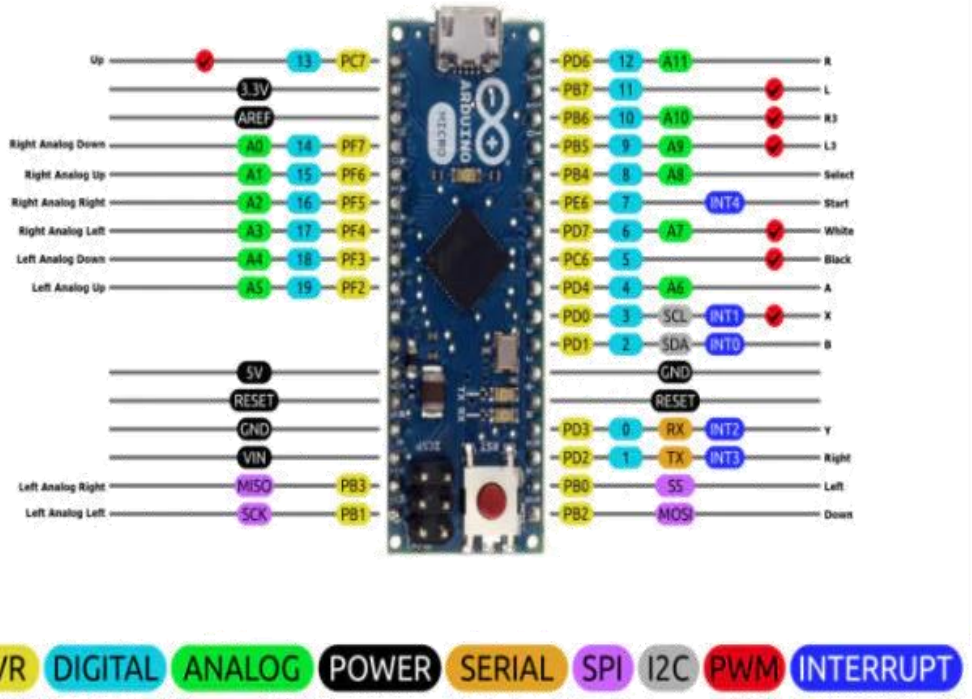
25 more Arduino shields [ref]

Arduino Microcontroller

- Arduino UNO widely used as starter board for small robotics hobby projects
- Arduino Micro board used in lab for IMU data interface
- Resources: GPIO, 10 bit ADC, 8 bit DAC with PWM, serial UART, SPI, I2C



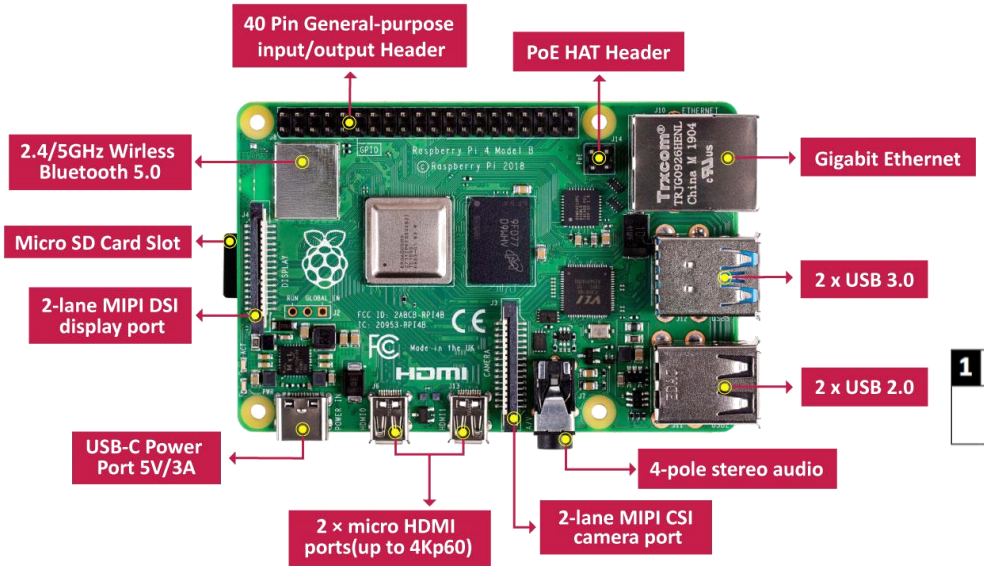
Arduino Uno board resources [ref]



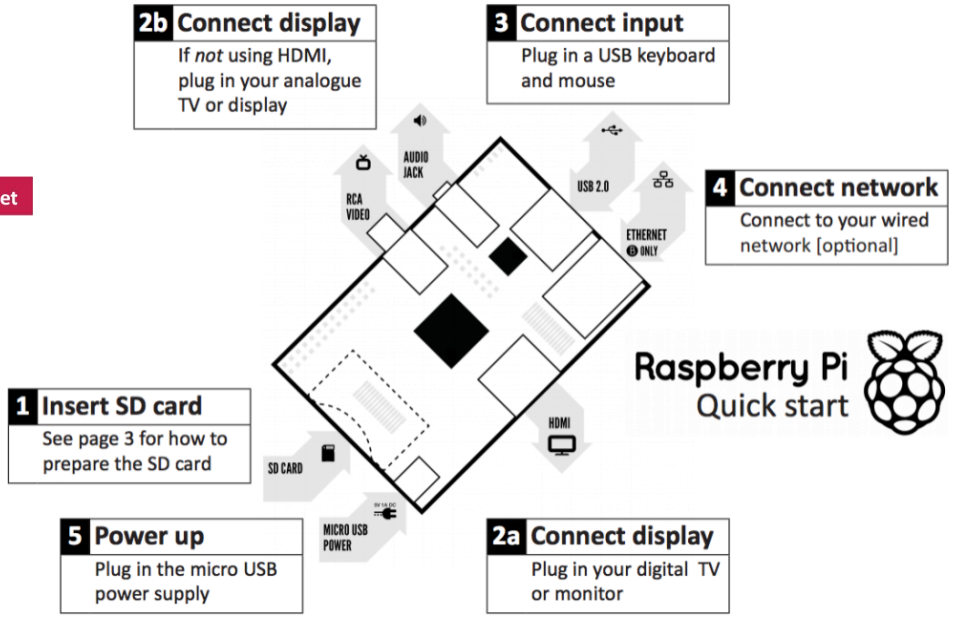
Arduino Micro board resources [ref]

Raspberry Pi

- Cost-efficient mini-computer with SD card for memory
- Allows easy installation and modification of operating system
- Significantly higher processing capability compared to Arduino
- More GPIOs but no ADC/DAC ports included in the original design
- Use with Linux operating system in various robotics projects



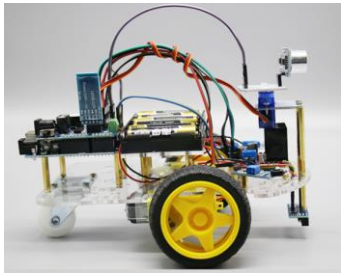
Raspberry Pi 4 diagram [ref]

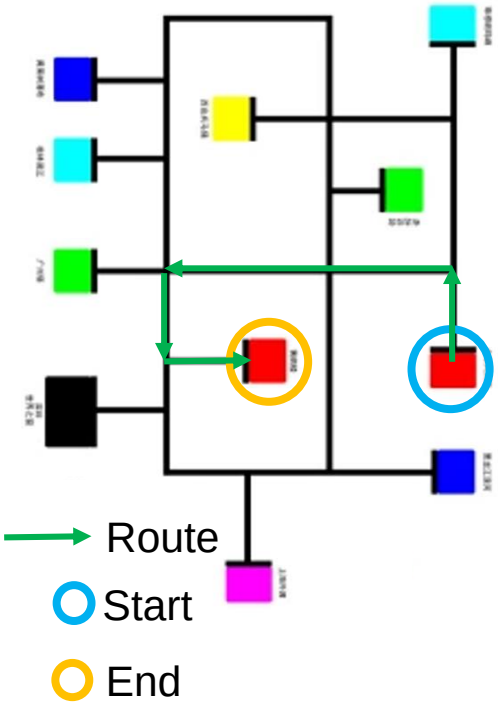


Raspberry Pi quick start guide [ref]

Pokemon Robotics Challenge

- Mobile Robot Platform
  - Line following, ultrasonic distance, obstacle avoidance, optical encoder, grey scale sensors
  - Go to stop with same color as start to catch the Pokemon





Sensors for the Robot

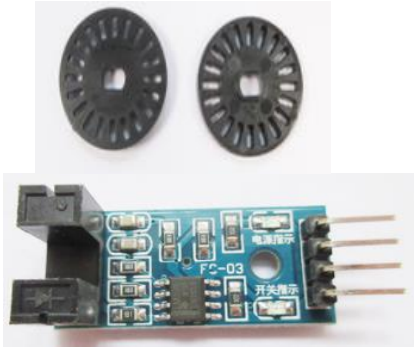
- Ultrasonic Distance Sensor
  - Trig: send pulse, Echo: measure return signal delay
- Infrared sensor
  - 1 channel digital signal for obstacle avoidance
  - 4 channel digital line following sensor
- Color sensor
  - Analog signal output measuring greyscale color
- Optical encoder
  - Used for counting rotation roughly
  - Count changes of digital signal (20 slots on the plate)

Ultrasonic distance

Infrared sensor

4 channel line following

Grey scale sensor



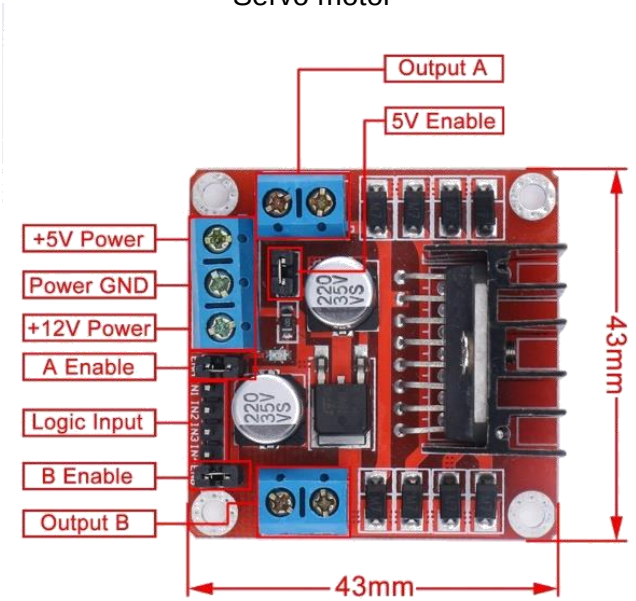
Optical encoder set

Motor Driver Wiring

- Servo motor: angle control 0-180
  - Red/Brown: positive/negative
  - Orange: angel control signal
- Direct current motor:
  - Continuous rotation of wheels
  - L298N motor driver for current supply

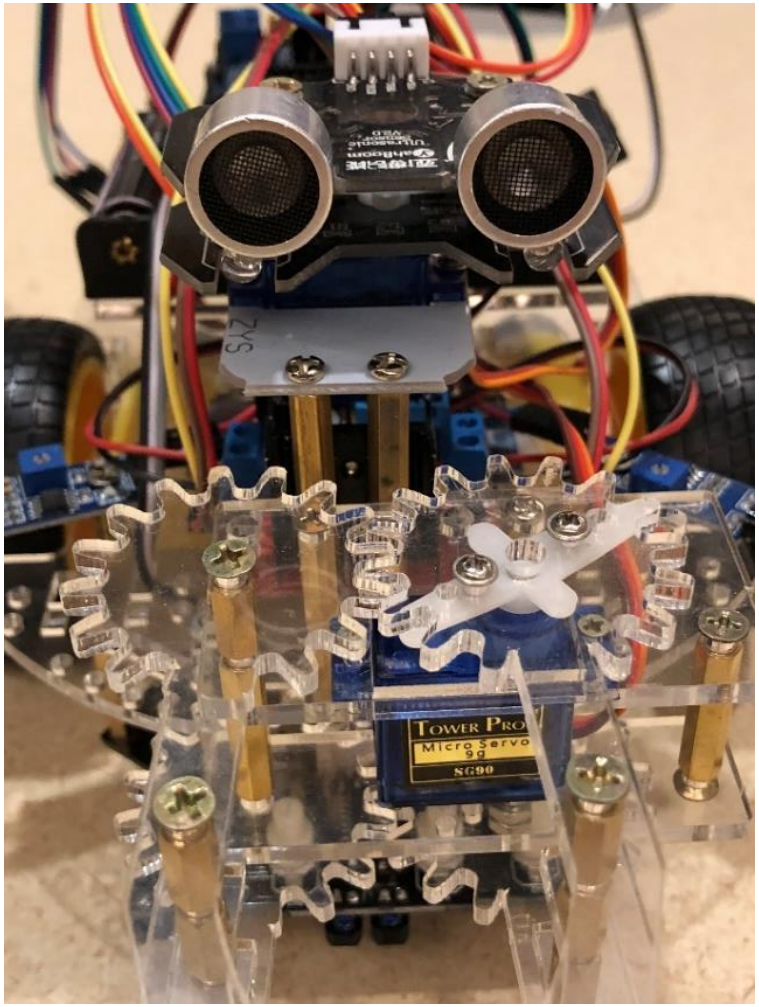
Servo motor

Geared DC Motor

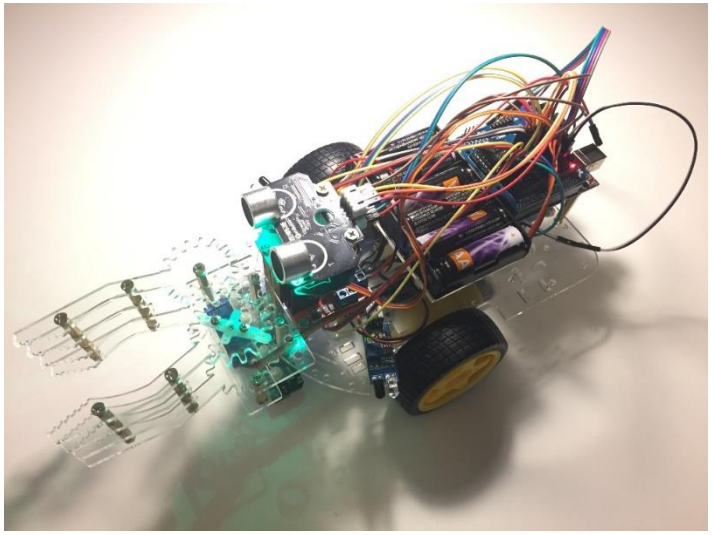


L298N motor driver

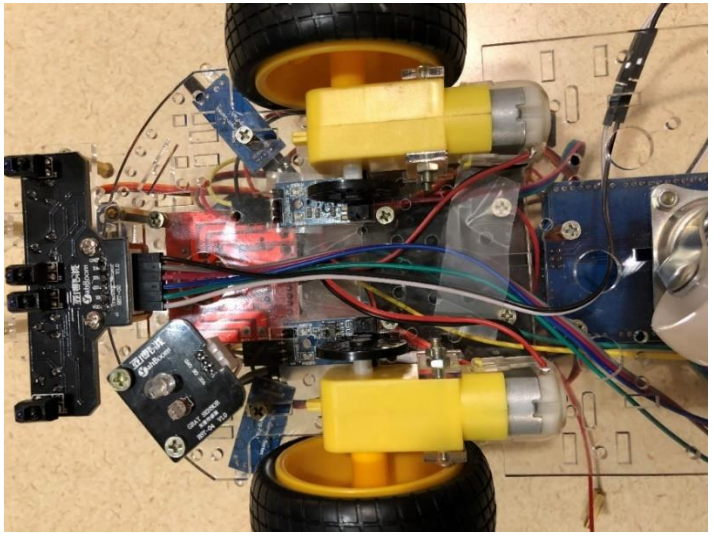
Assembled Robot



Robot front view



Robot isometric view



Robot bottom view

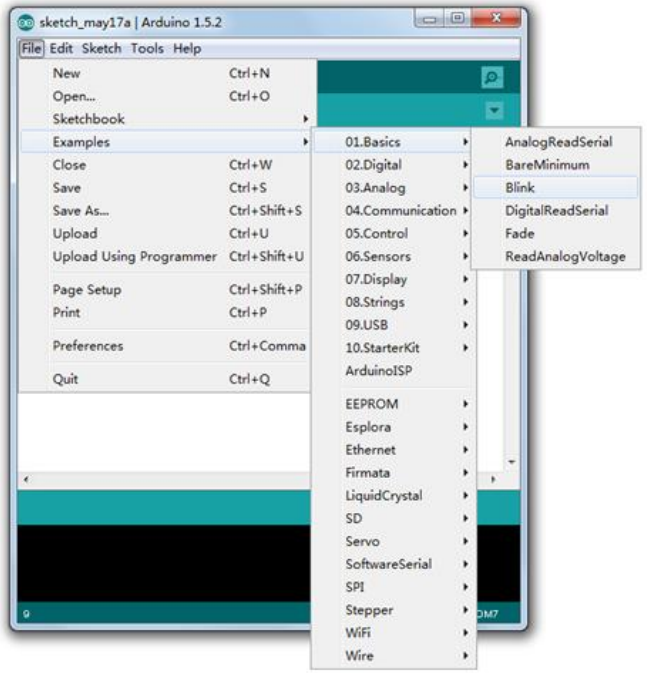
Control and Programming

Arduino Microcontroller Resources Summary

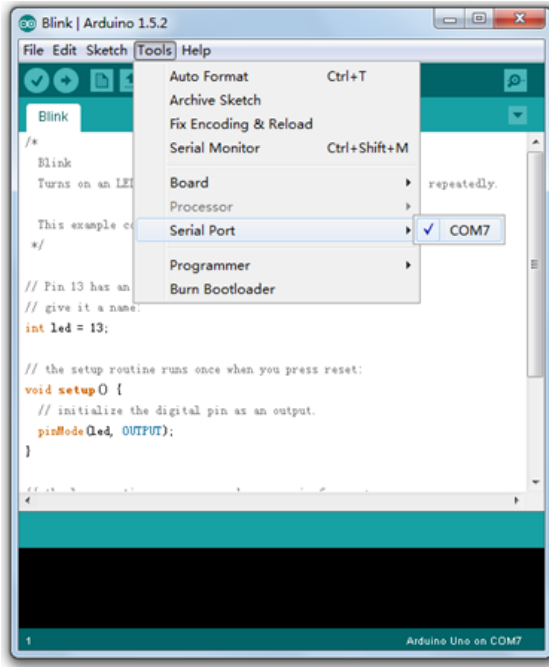
- General-Purpose Input/Output (GPIO)
  - Uncommitted digital signal pin configured for either input or output
- Analog to Digital Converter (ADC)
  - Read analog sensor signal as digital values for microcontroller processing
- Digital to Analog Converter (DAC)
  - Convert microcontroller digital values to analog voltage signal
  - Pulse Width Modulation: approximate with high frequency switching of GPIO
- Interrupt: handling of special events with higher priority
- Communication Protocols: (UART, SPI, I2C, GPIB, SCSI, etc.)
  - Universal Asynchronous Receiver/Transmitter (UART) communication
  - Serial Peripheral Interface (SPI) communication
  - Inter-Integrated Circuit (I^2C) communication
- Application Dependent Peripherals
  - Analog signal conditioning and digital signal processing blocks
  - Communication protocol handling blocks: Bluetooth, Ethernet, Wifi, etc.
  - Direct Memory Access blocks, sensor/actuator driving electronics

Arduino Software Interface

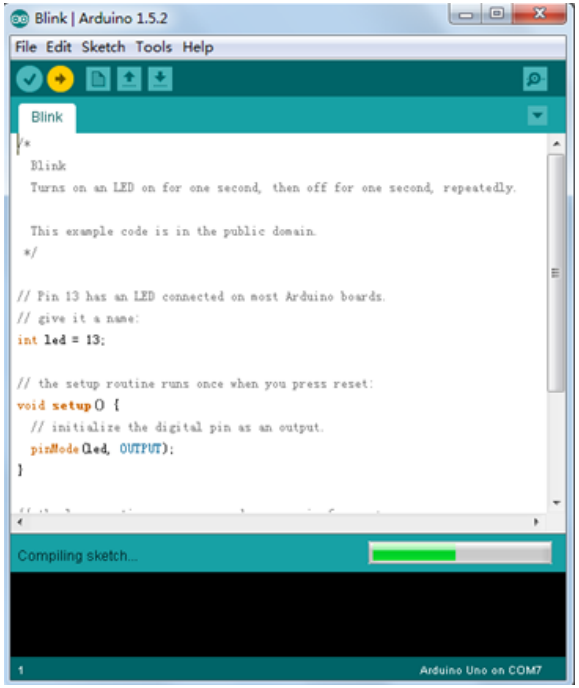
- Download, install and open the Arduino Integrated Development Environment
- Select an example from the drop down for board testing
- Select the serial port for the board and change the board time as needed
- Click on the arrow to upload the code (confirm success at the status bar)



Arduino IDE example



Arduino serial port/board selection



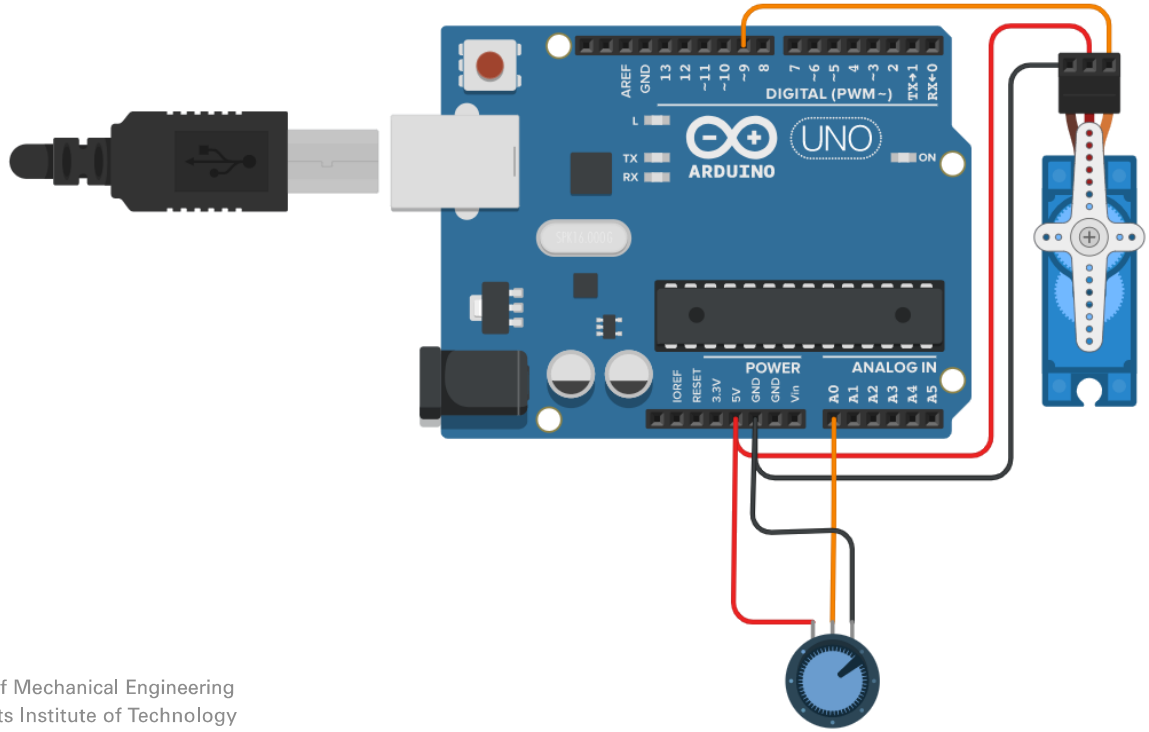
Arduino code upload

Arduino Programming Reference

- Automate register level manipulation with built-in function for easy coding
- C/C++ based programing style with specific features for the microcontroller
- Good documentation online and examples with the IDE
- Various libraries available for operation with external shields and devices
- Code general structure: setup() and loop() function
  - void setup(): Initializing variables and modes of Pins
  - void loop(): Run program inside this function continuously
- Digital input and output functions (pin definition for UNO as pin: 0~13, A0~A5)
  - Set pin mode: void pinMode(pin, mode); mode: INPUT | OUTPUT
  - Output voltage level: void digitalWrite(pin, value); value: HIGH | LOW
  - Input voltage level: int digitalRead(pin); value: HIGH | LOW
- Analog input and output functions (UNO AI pins: A0~A5; AO pins: 3,5,6,9,10,11)
  - Analog input: int analogRead(pin); integer range 0 to 1023
  - PWM analog output: void analogWrite(pin, value); integer range 0 to 255
- Serial functions: Serial.begin(baud rate); Serial.read(); Serial.println(text);
- Timing functions: void delay(ms); void delayMicroseconds(us):

Exercise: Servo Motor Control

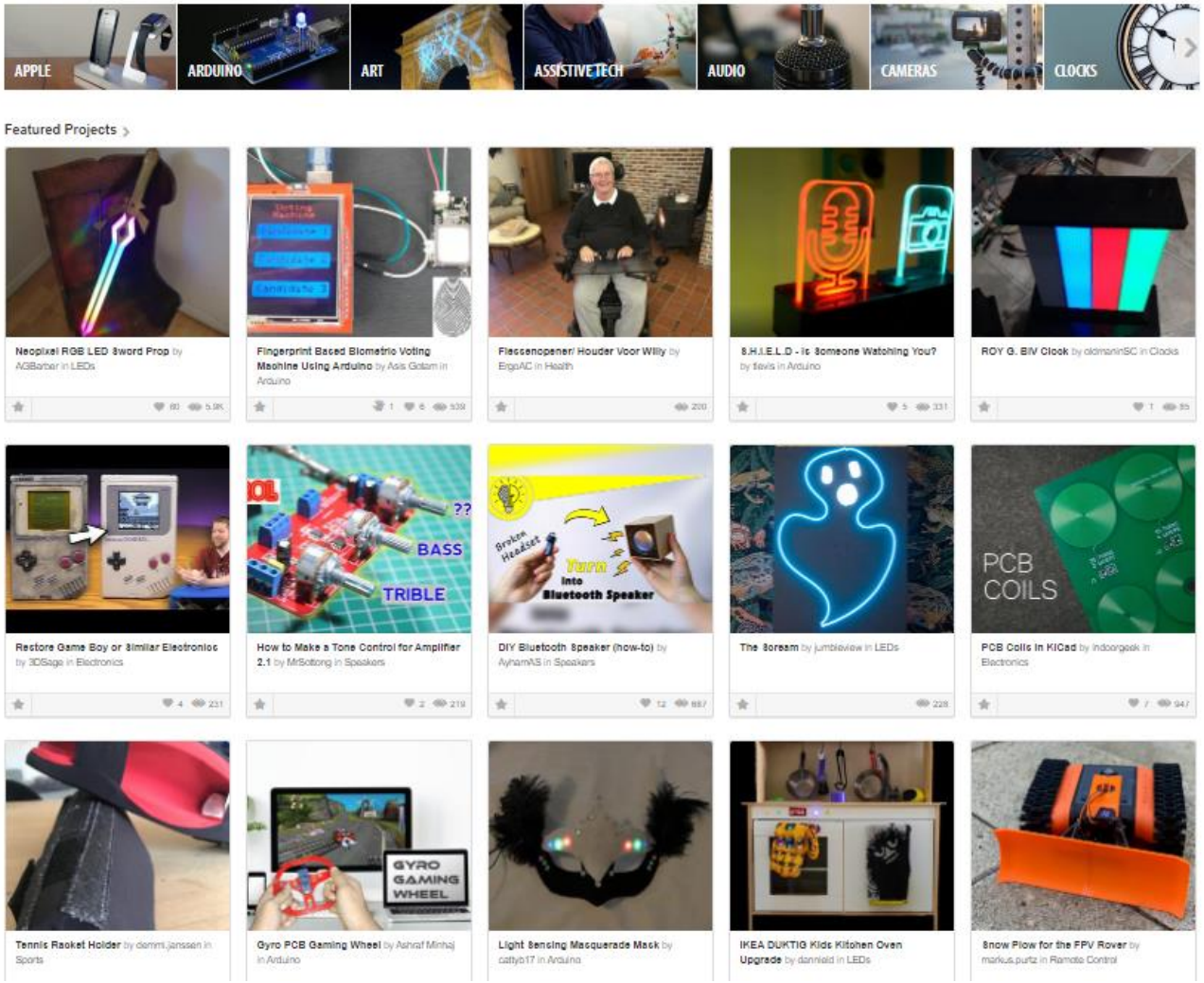
- We are going to control the servo motor angle with a potentiometer
- Go to TinkerCAD and register an account: https://www.tinkercad.com/
- Log into TinkerCAD and select circuit
- Create a circuit with Arduino Uno R3, Potentiometer and Micro Servo
- Follow the demonstration to implement the code



Final Servo Code

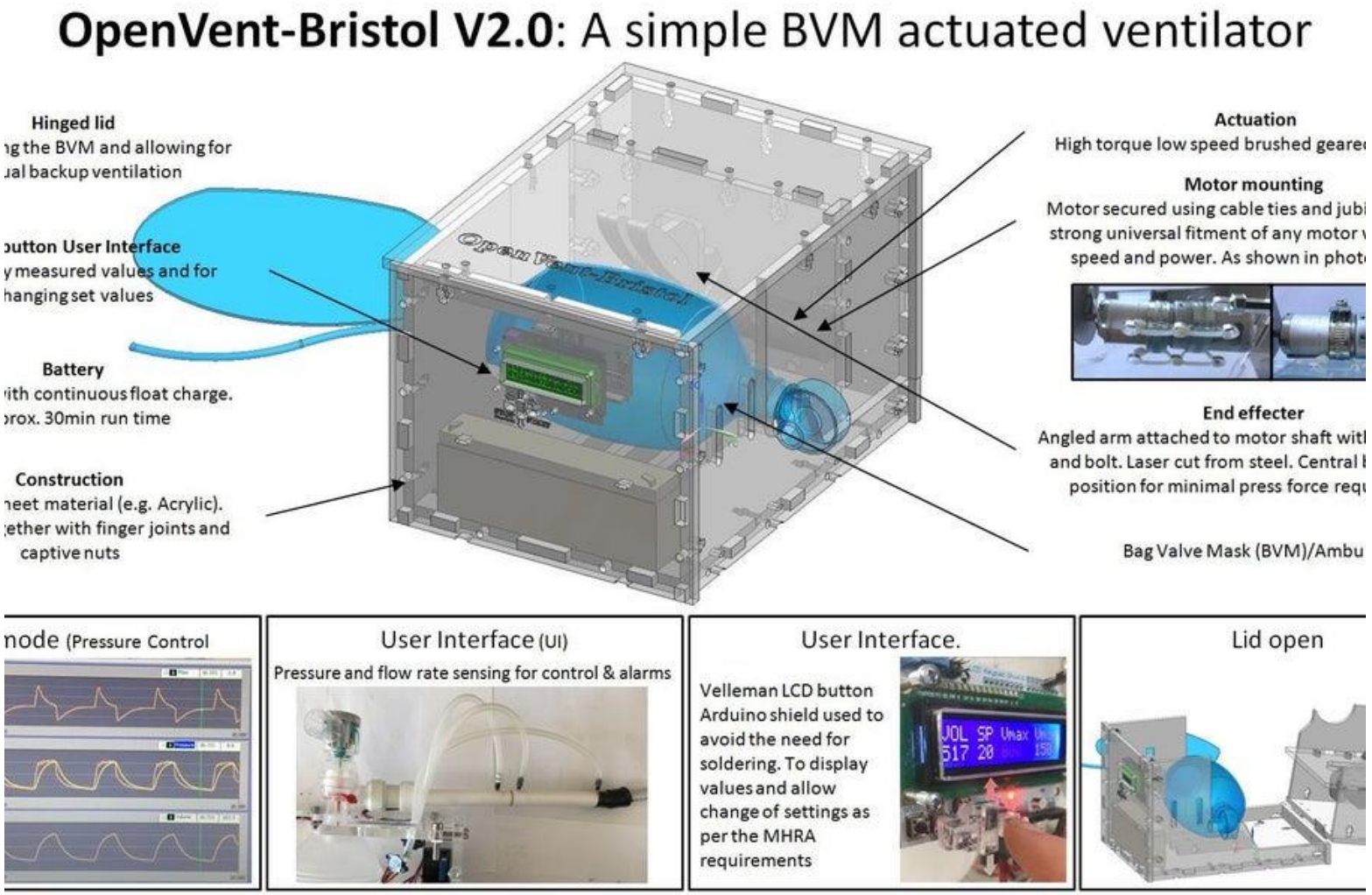
```
#include <Servo.h>                                  // library for the servo motor
int pos = 0;                                        // initialize servo position variable
int angle = 0;                                      // initialize angle record variable
Servo servo_9;                                      // create a servo variable

void setup() {                                      // setup function that runs once
  servo_9.attach(9);                                // create the servo motor on pin 9
  pinMode(A0, INPUT);                               // set the A0 pin mode to input
  Serial.begin(9600);                               // start a serial port at 9600 baud rate
}

void loop() {                                       // loop function that runs forever
angle = analogRead(A0);                             // read potentiometer from A0
  Serial.println(angle);                            // display the angle value through serial
  servo_9.write(map(angle,1023,0,0,180));           // set the servo angle with mapping
  delay(10);                                        // wait for 10 milliseconds
}
```

Project Ideas on Instructable



Instructable page for project ideas [ref]

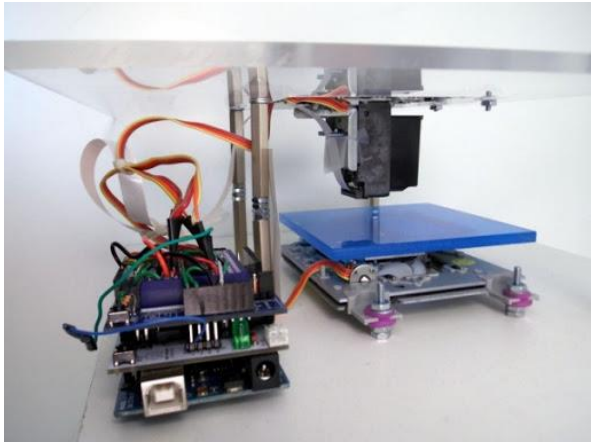
Ventilator Project Example

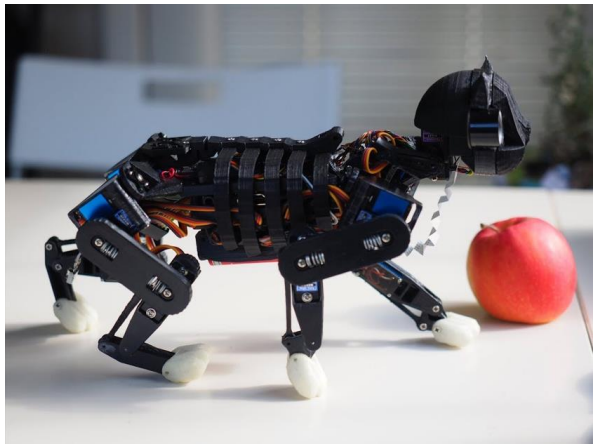


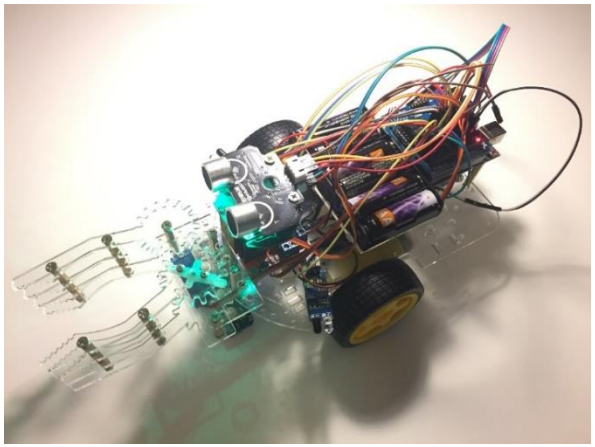
OpenVent-Bristol V2.0 bag valve mask ventilator [ref]

Software Tools for Mechatronics

- Instructable, Hackster.io, edX, Udemy, PacktPub, Coursera, ROS Ignite Academy
  - Design：Solidworks, OnShape, Fusion 360, AutoCAD, UG NX, Catia
  - Analysis: Ansys, Abaqus, Altair Hyperworks, COMSOL, ADAMS
  - Embedded Systems：Arduino, Raspberry Pi, STM+FPGA, LabVIEW
  - Electronics: Altium Designer, Multisim/Ultiboard, Eagle
  - Programming: Python, Matlab/Simulink, Origin, C/C++, Java, JavaScript, R
  - Robotics: ROS, TensorFlow, PyTorch, OpenAI Gym, Keras, OpenCV
  - Documentation: PPT, Adobe PS, Adobe AI, Visio, Word, LaTeX
  - Video: VideoStudio, Adobe Premiere/AfterEffect, Camtasia, Cinema 4D, 3DS Max







Thank You!