Autonomous Systems Lab

What Are Autonomous Systems?

An autonomous system is one that can achieve a given set of goals in a changing environment—gathering information about the environment and working for an extended period of time without human control or intervention. Driverless cars and autonomous mobile robots (AMRs) used in warehouses are two common examples.

Autonomy requires that the system be able to do the following:

- Sense the environment and keep track of the system's current state and location.
- Perceive and understand disparate data sources.
- Determine what action to take next and make a plan.
- Act only when it is safe to do so, avoiding situations that pose a risk to human safety, property or the autonomous system itself.

By: https://blackberry.qnx.com/en/ultimate-guides/autonomous-systems

Sensors Used in Autonomous Systems

Sensors help an autonomous system determine its location, identify informational signs, and avoid obstacles and other hazards. The use of multiple sensors can overcome a weakness of one type of sensor by pairing it with another one with different strengths and weaknesses.

- **Camera sensors:** Video and still-image cameras are common types of optical sensors. Multiple cameras can provide a 360° view of the environment.
- **Ultrasonic sensors:** Ultrasonic sensors use high frequency sound waves to estimate distances between the sensor and an object. Ultrasonic sensors are typically used in short-distance applications
- **Infrared sensors:** Infrared sensors provide images under low-lighting conditions, such as those in night-vision systems.
- **LiDAR sensors:** LiDAR sensors use lasers to estimate distance and create high-resolution 3D images of the environment. Rotating LiDAR systems offer a full 360° view around an autonomous device.
- **Radar sensors:** Using short-range (24 GHz) and long-range (77 GHz) radio waves, radar sensors monitor blind spots in autonomous vehicles for safer distance control and braking assistance applications.

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Additional Sensors Used in Autonomous Systems

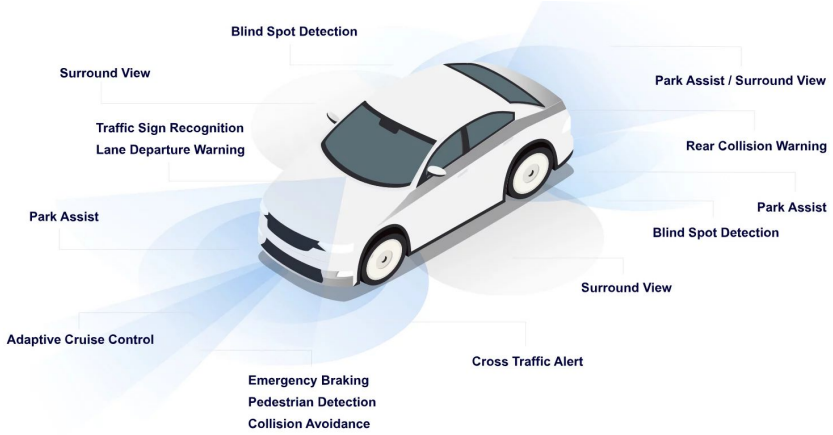
- **Accelerometer sensors:** Accelerometers measure changes in speed. Accelerometers are used for orientation, slope and collision detection.
- **Gyro sensors:** Gyro sensors measure orientation and angular velocity. A gyro sensor uses a spinning disk that pivots and self-orients with respect to Earth's gravity. Gyro sensors help maintain direction in applications such as tunnel mining and aerospace.
- **IMU sensor:** An inertial measurement unit (IMU) uses gyro sensors and accelerometers to measure position and orientation.
- **Inertial navigation system:** An inertial navigation system (INS) includes an IMU and is used to estimate vehicle position, orientation and speed.
- **Global positioning** system (GPS) receiver: A GPS receiver is a type of sensor that identifies the position of the system in its local environment through satellite triangulation. GPS receivers are used with maps to estimate position, direction and speed.

By: https://blackberry.qnx.com/en/ultimate-guides/autonomous-systems

Sensor Fusion

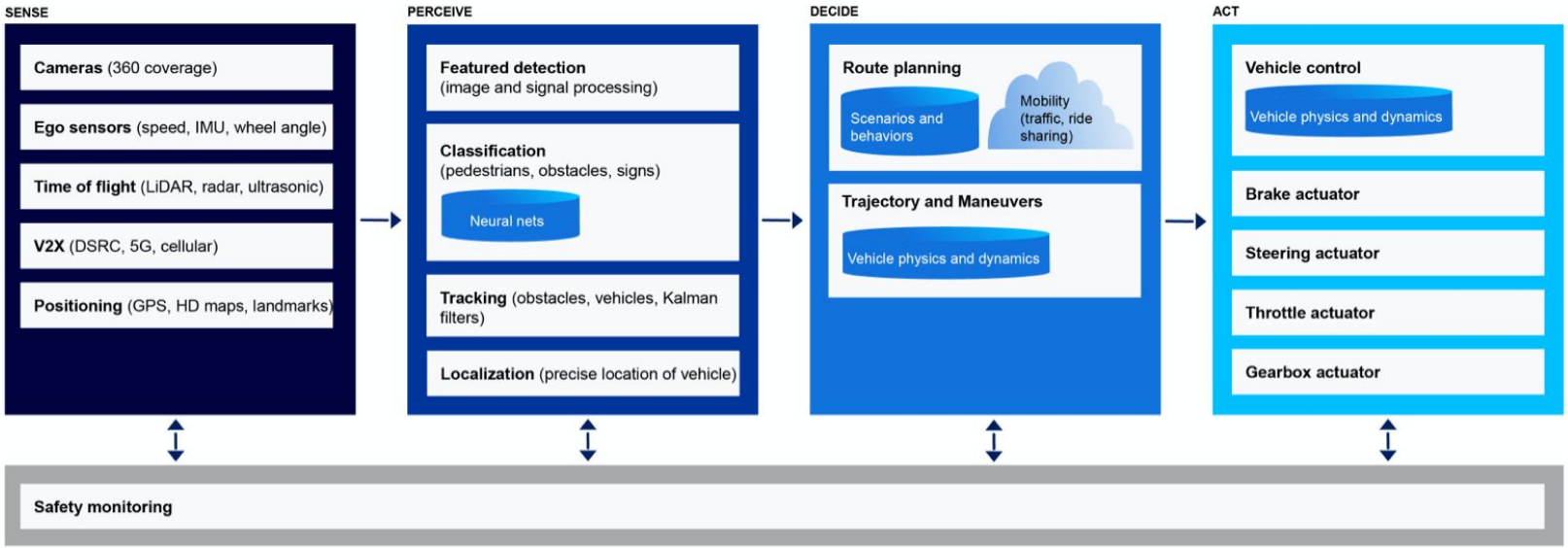
Each type of sensor and source of environmental information has advantages and disadvantages. Sensor fusion produces more detailed and more accurate information about the environment than could be achieved with a single source. As a branch of machine learning and signal processing that focuses on perception, sensor fusion combines data from multiple sensors and databases to produce higher-quality information so that an autonomous system can make better, safer decisions. Sensor fusion is also known as data fusion, filtering or target tracking.

Sensor fusion systems typically take data from cameras, LiDAR, radar, sonar and other sensors and fuse it together, essentially augmenting data from one type of sensor with data from another type of sensor.



By: https://blackberry.qnx.com/en/ultimate-guides/autonomous-systems

Examples of Autonomous Vehicle Platform Architecture



By: https://blackberry.qnx.com/en/ultimate-guides/autonomous-systems

The rise of autonomous control systems

Autonomous control means satisfactory performance under significant uncertainties in the environment and the ability to compensate for system failures without external intervention. This is different from automation, which is often defined as a process or procedure performed with minimal human assistance.

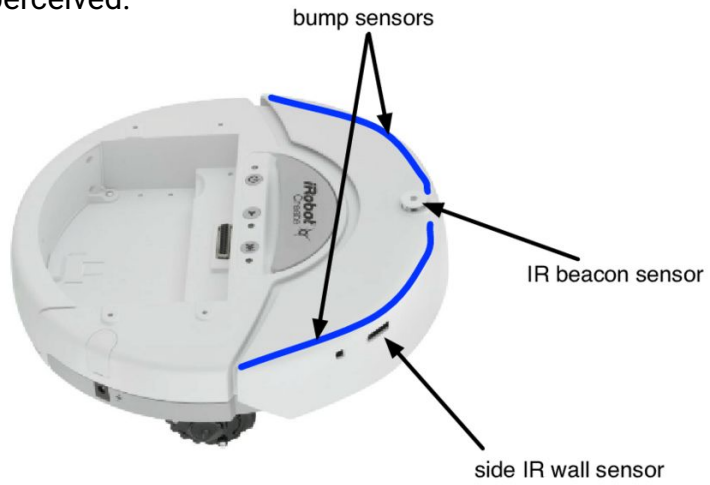
Autonomy and automation go hand-in-hand, boosting one another and providing a fallback for one another. For example, think of a remotely-operated ferry, piloted from shore (this is automation as opposed to autonomy). If communication with shore is lost for some reason, then an autonomous system that will bring the ferry to a safe state is a needed backup.

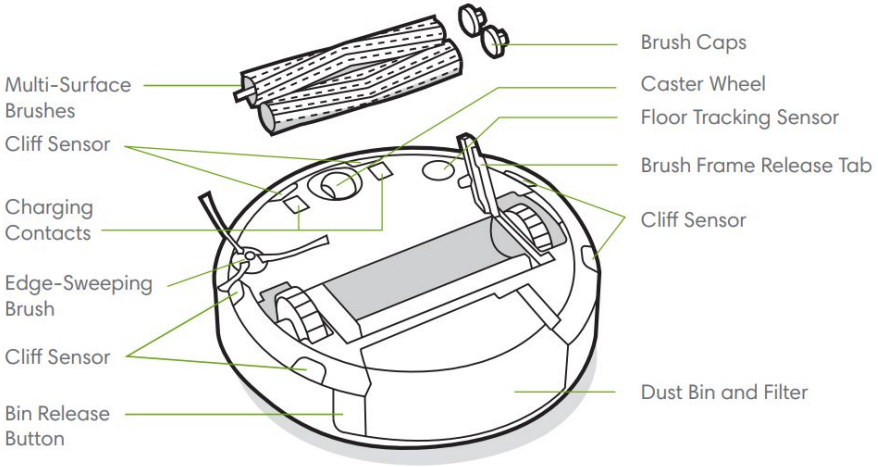
Advanced automation systems will become widely available in the near future. These will be automated processes that include a much higher level of self-correction thanks to the addition of sensors and feedback loops. Fully autonomous systems will first emerge in niche areas, especially when safety is not an issue. Such systems are already becoming available in some areas, including mining applications and food delivery.

By: https://www.dnv.com/to2030/technology/autonomous-control-systems.html

Why the Roomba is a Real Autonomous Robot

The Roomba can make decisions and act based on what it perceives in its environment. It can be placed in a room, left alone, and it will do its job without any help or supervision from a person. A set of sensors allows the Roomba to perceive its environment, decide a course of action based on these perceptions, and then take that appropriate action. Simply put, an autonomous robot is one that decides the action it should take on its own based on information it has perceived.





By: https://locusrobotics.com/what-are-autonomous-robots/

Lab Objectives

The lab objective is to introduce the development concepts for an autonomous system through hands on experience, while working with an assembled platform capable for autonomous behaviour, including:

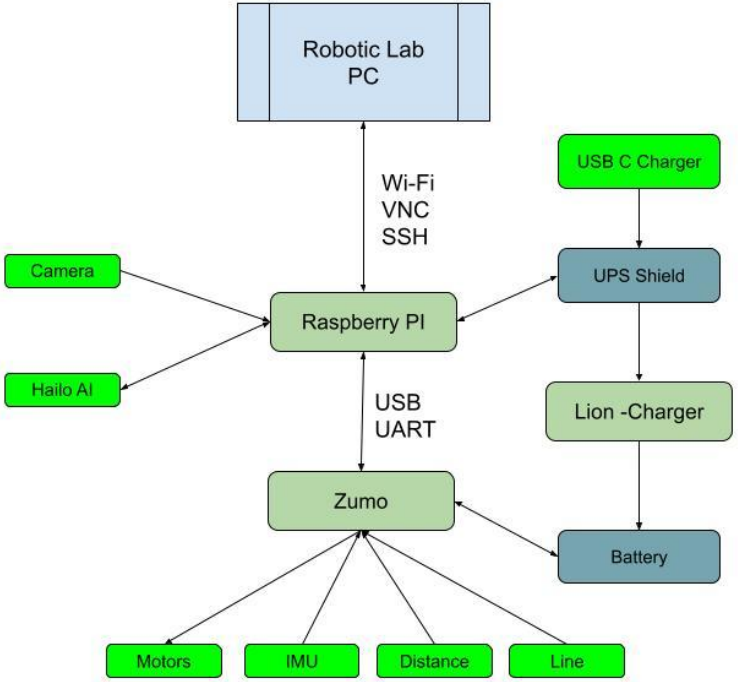
- Getting familiar with various sensors: Encoder, Camera, InfraRed distance, Accelerometer, Gyro, Magnomenter
- Writing and executing programs using C++ (Arduino) and python (Raspberry Pi)
- Analyzing sensor data
- Implementing sensor fusion
- Applying control algorithms and tuning parameters
- Introduction to various development environments: VS Code, Arduino, Secure Shell (SSH)
- Developing autonomous algorithms

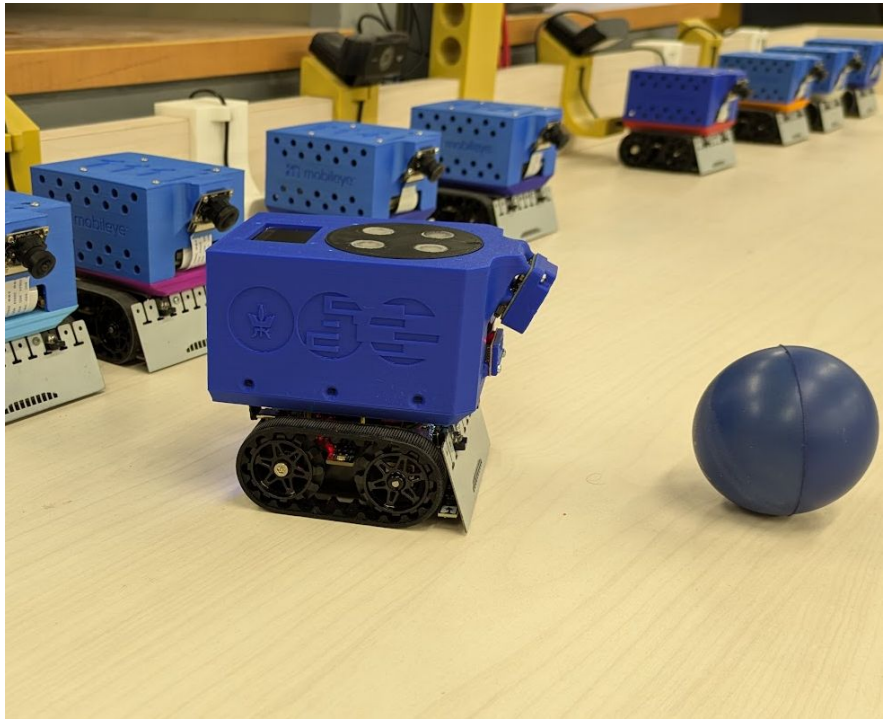
Final Project - Semester B 2025

The final project for this semester is: Line Following / Path Control

ZumoPi - Rover Platform

The ZumoPi platform is based on the Zumo platform by Pololu with an addition of a Raspberry Pi 5 PC

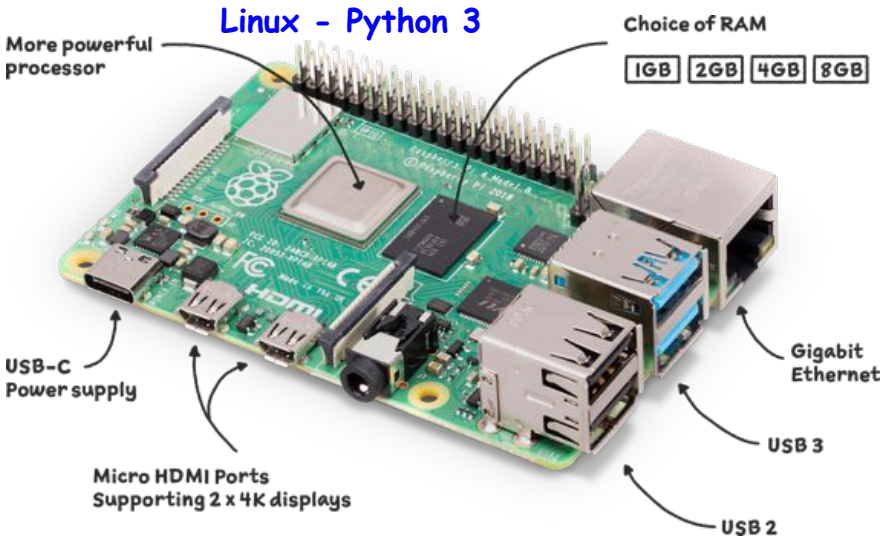


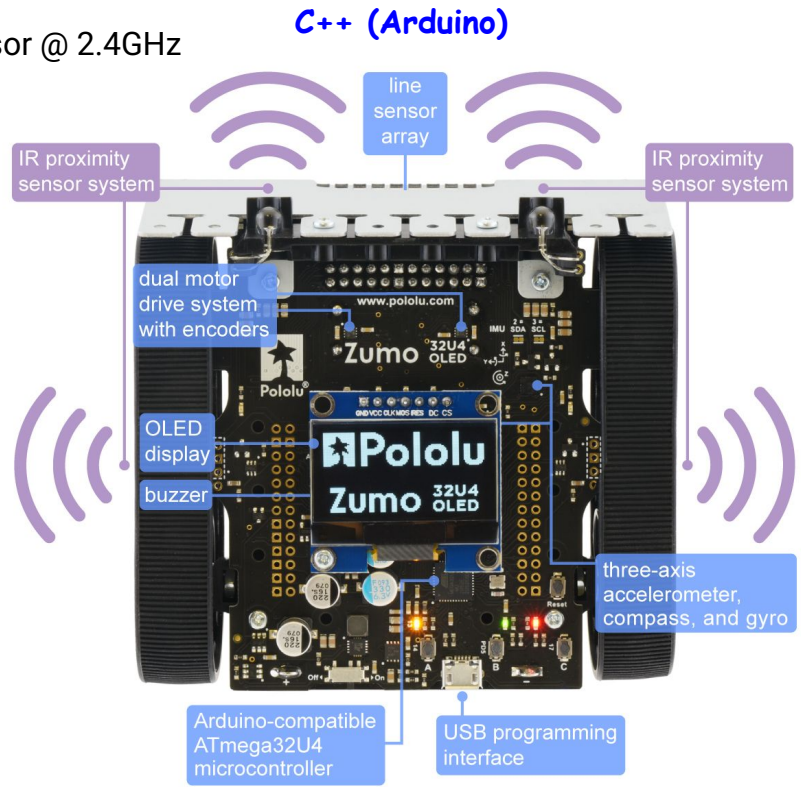


By: https://github.com/TALs-Education/ZumoPi

ZumoPi Main Components

- Raspberry Pi 5 - CM2712 quad-core Arm Cortex A76 processor @ 2.4GHz
- Zumo - RP2040 Dual ARM Cortex-M0+ cores @ 133 MHz



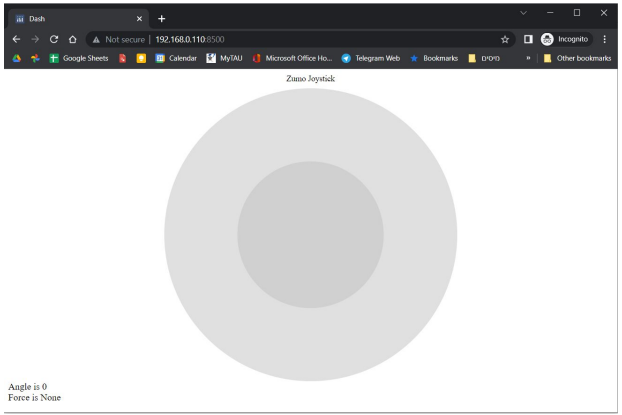


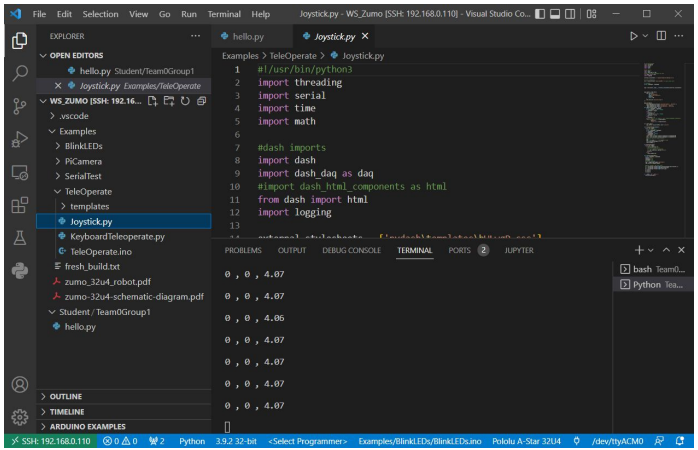
By: https://www.raspberrypi.org/

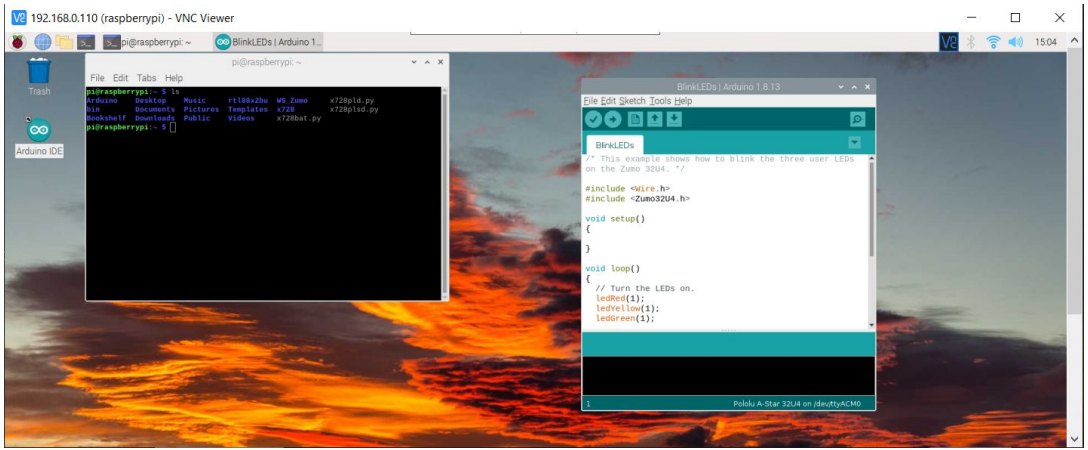
By: https://www.pololu.com/product/5012

Development Environments

- MobaXterm - SSH https://mobaxterm.mobatek.net/
- Arduino - C++ https://www.arduino.cc/
- VS Code - Python, C++ https://code.visualstudio.com/
- VNC (Virtual Network Computing) https://www.realvnc.com/en/
- Python https://www.python.org/
- Web Browser (User interface)



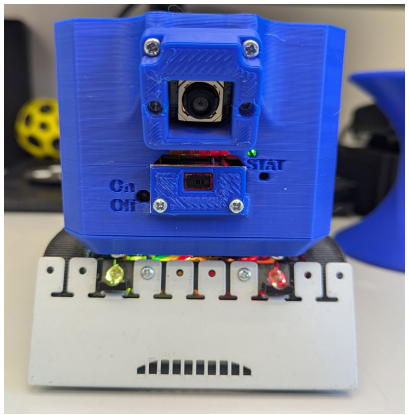


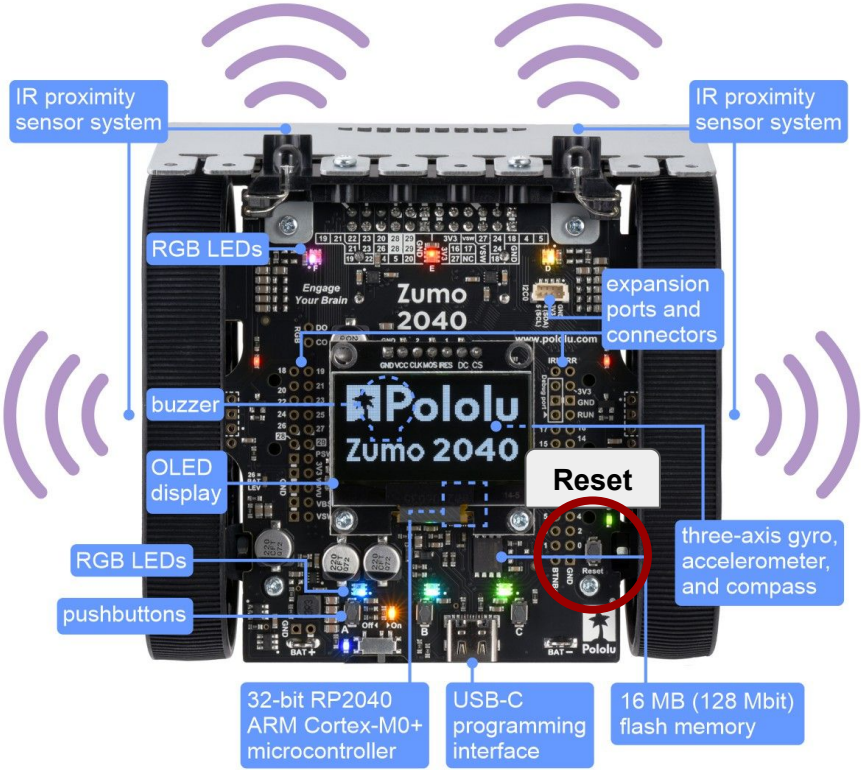


Practice 0 - Turn On the ZumoPi V02 Platform

- Turn on the platform by pressing the On/Off button
- Wait a minute and if needed, press the button again
- Press the Reset Button on the zumoPiV 02 (required after boot)

The ZumoPi V02 has a built in auto shutdown after 4 hours. Sometimes after boot the time is updated in a delay and the system will perform an unnecessary shutdown. Hence the second boot is required.





By: https://www.pololu.com/product/5012

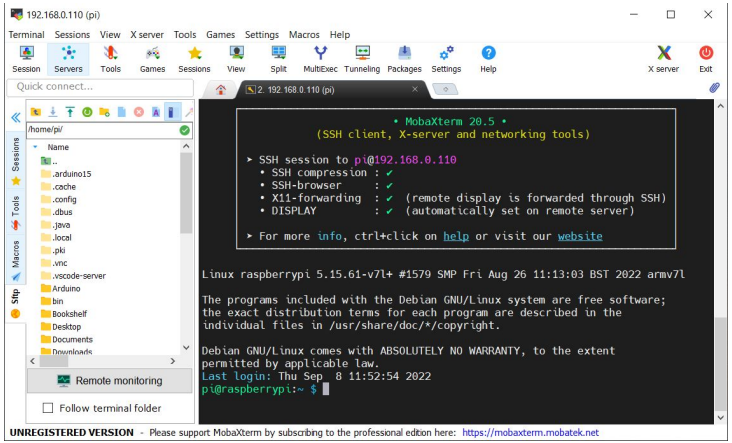
Practice 1 - Connecting to the platform over SSH (Secure Shell)

SSH is a network communication protocol that enables two computers to communicate and share data. An inherent feature of ssh is that the communication between the two computers is encrypted meaning that it is suitable for use on insecure networks

- Connect to the lab internal network: Controllab # Controllab
- Open command line interface and connect to the platform:
  ssh pi@192.168.0.1xx Password : zumo

MobaXterm is an enhanced terminal for Windows with X11 server, tabbed SSH client, network tools and much more

- Launch MobaXterm (download and install if necessary)
- Connect to the platform by opening a new session

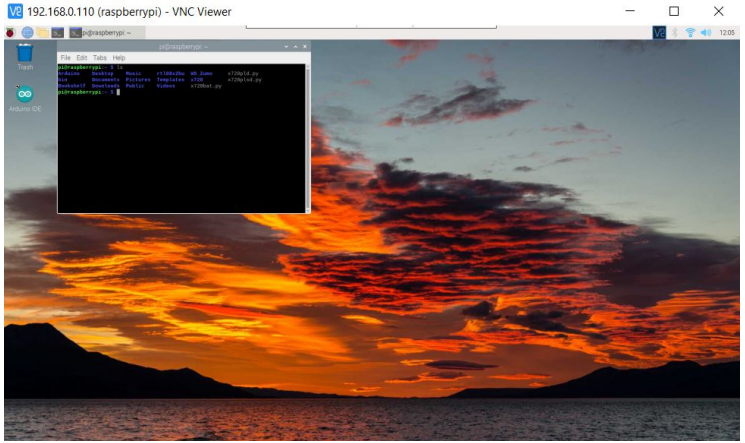


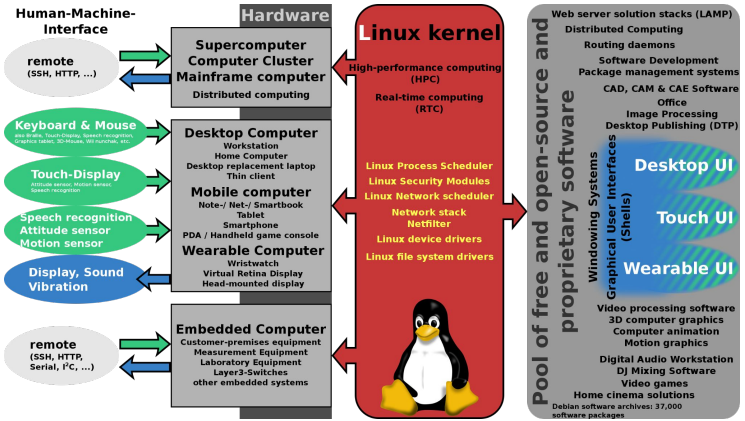
By: https://www.ucl.ac.uk/isd/what-ssh-and-how-do-i-use-it , https://mobaxterm.mobatek.net/

Linux Environment - Raspberry Pi OS

Linux is a family of open-source Unix-like operating systems based on the Linux kernel, an operating system kernel first released on September 17, 1991, by Linus Torvalds. Linux is typically packaged in a Linux distribution. Popular Linux distributions include Debian, Fedora Linux, and Ubuntu, which in itself has many different distributions and modifications, including Lubuntu and Xubuntu

Raspberry Pi OS (previously called Raspbian) is the official supported operating system for the raspberry pi. Raspberry Pi OS is a free operating system based on Debian optimized for the Raspberry Pi hardware. Raspbian provides more than a pure OS: it comes with over 35,000 packages, pre-compiled software bundled in a nice format for easy installation on your Raspberry Pi.

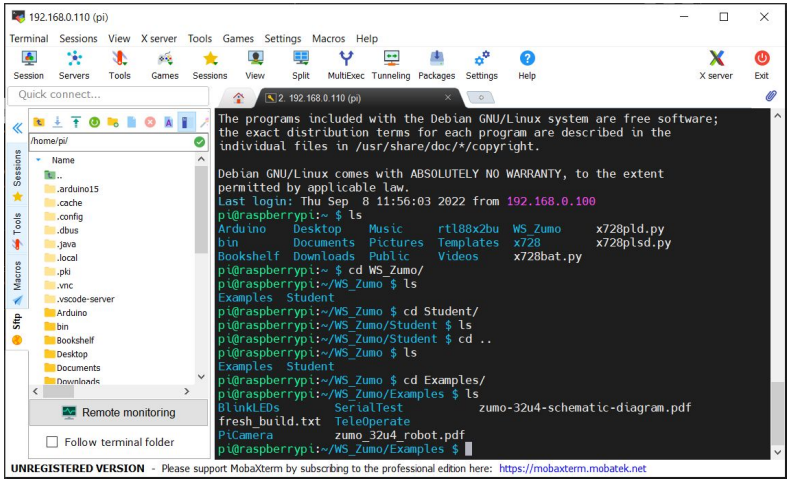




By: https://en.wikipedia.org/wiki/Linux , https://www.raspbian.org/ , https://www.raspberrypi.com/software/

Practice 2 - Basic Unix Commands

- **ls** --- lists your files
- **ls -l** --- lists your files in 'long format', which contains lots of useful information
- **ls -a** --- lists all files, including the ones whose filenames begin in a dot
- **ls -help** --- prints the help manual page for the command
- **man ls** --- shows you the manual page for the command
- **cd dirname** --- change directory. You basically 'go' to another directory, and you will see the files in that directory
- **cd ..** --- change to the parent directory
- **pwd** --- tells you where you currently are
- **chmod options filename** --- lets you change the read, write, and execute permissions on your files.
- **sudo reboot** --- Performs system reboot

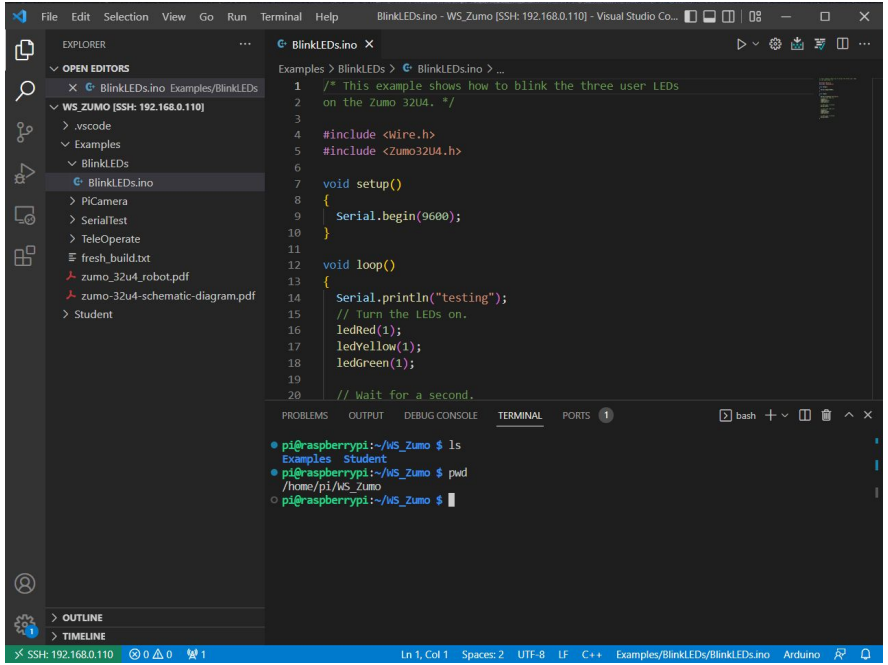


By: https://mally.stanford.edu/~sr/computing/basic-unix.html

Setting up VS Code

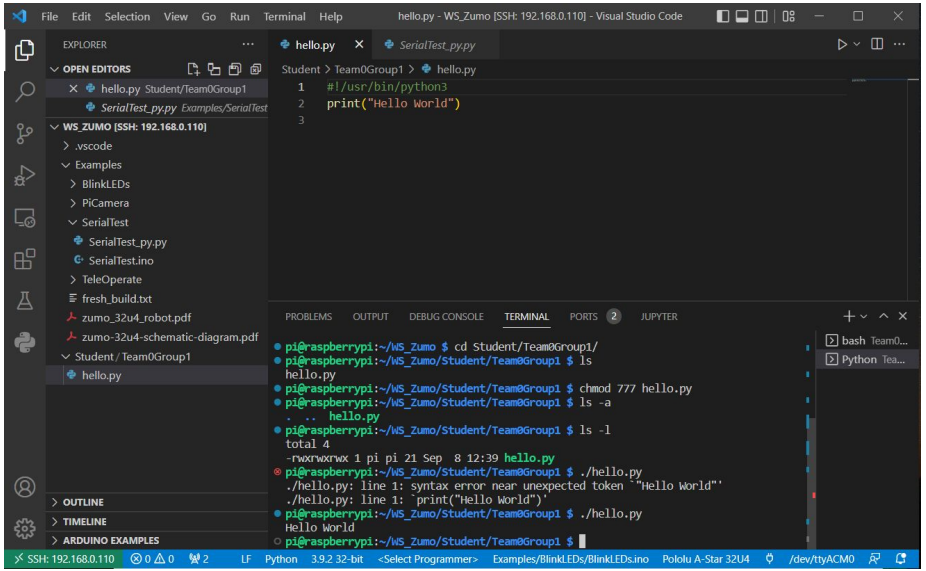
Visual Studio Code, also commonly referred to as VS Code, is a source-code editor made by Microsoft for Windows, Linux and macOS. Features include support for debugging, syntax highlighting, intelligent code completion, snippets, code refactoring, and embedded Git. Users can change the theme, keyboard shortcuts, preferences, and install extensions that add additional functionality.

- Install VS Code (if needed)
- Add the following extensions (if needed):
  - C/C++ (Microsoft)
  - Python (Microsoft)
  - Remote - SSH (Microsoft)
- Connect to the platform
  - Connect to a host → Your platform Ip
  - Add new SSH Host (If needed)
- Open Folder → WS_Zumo



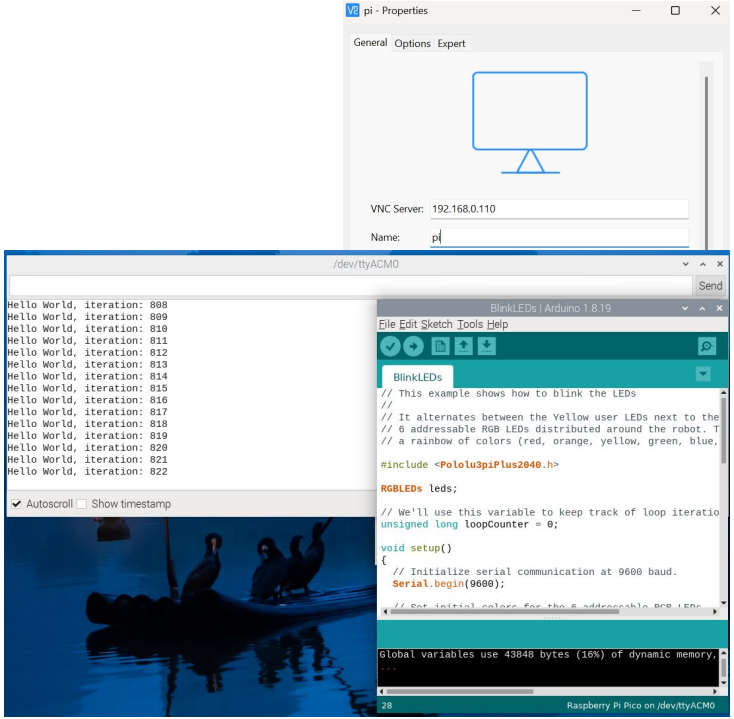
Exercise 1 - Raspberry pi

- Navigate to /home/pi/WS_Zumo/Student
- Create a new folder with your group number / name
- Write a Hello world script in python and execute it. The program should print a Hello World string to the command line interface.
- Methods for execution:
  - python hello.py
  - ./hello.py (if file is executable)
  - Play button in VS Code if extension for python is installed



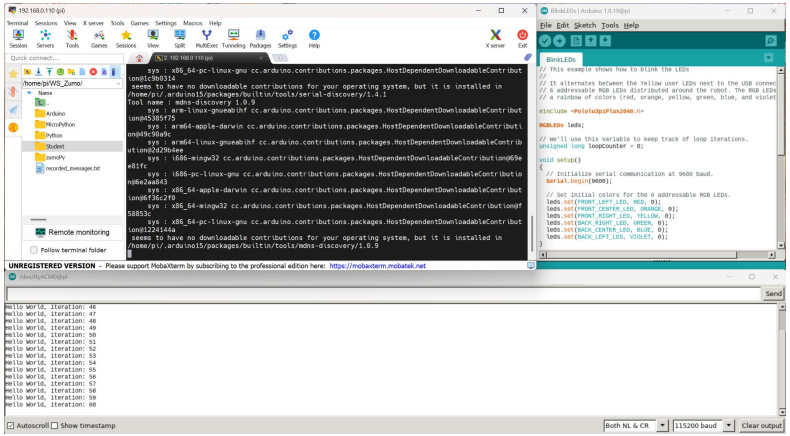
Practice 3 - VNC (Virtual Network Computing) & Arduino

- Install VNC Viewer (if needed) https://www.realvnc.com/en/
  - Connect to the platform desktop environment
  - User name: pi
  - Password: zumo
- Run Arduino IDE on the Raspberry Pi
  - Open Led blink example File→Open
  - Pi/WS_Zumo/Arduino/Examples/BlinkLEDs/BlinkLEDs.ino
  - Upload the the code and notice the Leds
  - Open the Serial Monitor and notice the text
- Save the code in your group folder:
  - Pi/WS_Zumo/Student/<Folder>/BlinkLeds/BlinkLEDs.ino
  - **Close everything before proceeding**



Practice 3 - Continue

- Open mobaXterm and connect to the platform
  - Run **arduino** command in the terminal
  - An Arduino IDE interface will be opened on the pc by the X11-forwarding protocol available in MobaXterm
  - Upload the code again and view the serial monitor
- Upload code using Arduino CLI - (Command Line Interface)
  - Navigate to the code using a terminal
  - cd WS_Zumo/Student …
  - Compile and upload the code using aliased commands: **(Close Serial Monitor between Methods)**
    - zumoCompile BlinkLEDs.ino
    - zumoUpload BlinkLEDs.ino
- Modify the code and see the changes applied



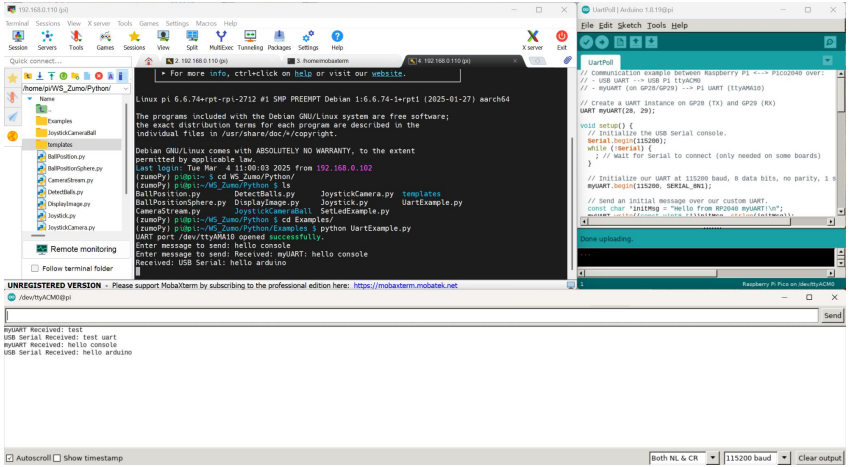
Exercise 2 - Arduino

- Based on the led example write a program for a sequence blinking and execute it using the various methods:
  - Arduino IDE through VNC connection
  - Arduino Cli using mobaXtem
  - VSCode (if extension is installed)
    - Which method is the easiest / most intuitive?
    - Which method uses the most resources of the raspberry pi, which the least? (by your opinion)
    - Run **htop** command in terminal to notice resources consumption for various setups.
- Write a new code which will send messages to the serial port with a counting number
  - Test the Serial Monitor using Arduino IDE
  - Test the Serial Monitor using VS Code (if extension is installed)

Only one Serial connection may be open at a time

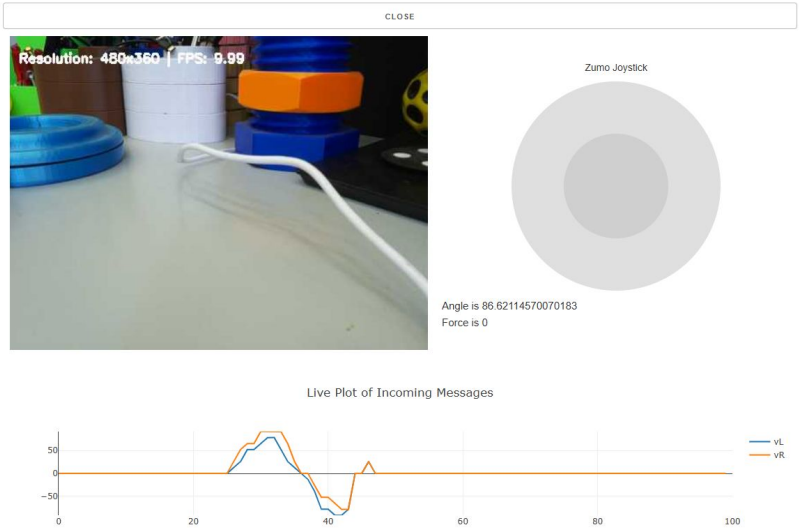
Practice 4 - Serial communication

- Upload UartPoll.ino code to the microcontroller
  - Using the Terminal navigate to ~/WS_Zumo/Arduino/Examples/UartPoll
  - Compile and upload the code SerialTest.ino using Arduino CLI commands.
- Run UartExample.py under ~/WS_Zumo/Python/Examples
  - Write messages in arduino Serial Monitor and python console and see what happens.
  - Explore the codes and understand the workflow



Practice 5 - Teleoperation

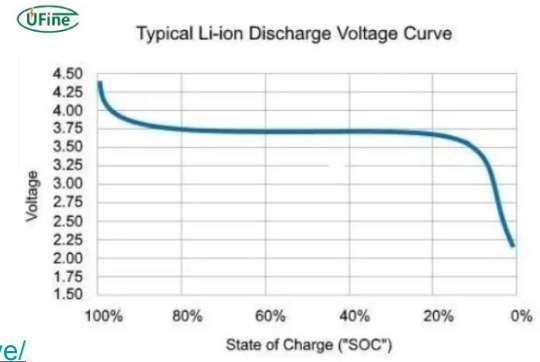
- Upload TeleOperate.ino code to the microcontroller
  - Using the Terminal navigate to ~/WS_Zumo/Arduino/Examples/Teleoperate
  - Compile and upload the code TeleOperate.ino using Arduino CLI commands.
- Run JoystickCamera.py directly or through an aliased command **zumoJoystick**
  - Using the browser navigate to the ip address of your platform using port 8500 i.e 192.168.0.110:8500
  - Press Button A on the Zumo platform and switch on the power switch on the Zumo
  - Check that your platform moves, open the serial monitor to see the debug messages.



Practice 6 - ZumoPower

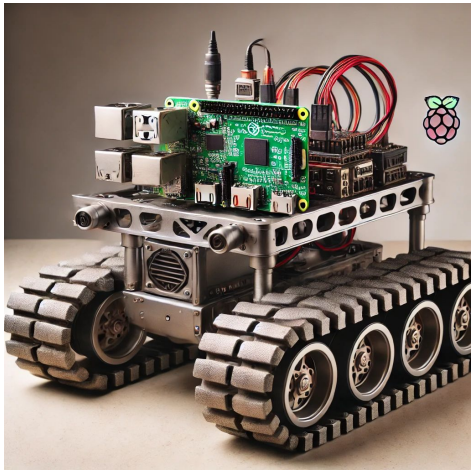
- The zumo platform has 2 batteries.
  - One powers the raspberry pi, which in turn powers the zumo platform over usb. Excluding the motors.
  - The second one powers the zumo platform including the motors. (Zumo platform will be powered from either source but the motors require the battery source for operation.
- To view the remaining charge of the batteries:
  - Run zumoPower aliased command in terminal to view the Raspberry Pi battery status.
  - Compile and run the BatteryStatus.ino for the microcontroller to see the remaining battery of the motors.
- Both batteries are lithium-ion type. Meaning full charge voltage is 4.2V. Mid status at 3.7V and depleted at around 3V. For additional information look for [lithium-ion discharge curve](https://www.ufinebattery.com/blog/how-to-read-lithium-battery-discharge-curve-and-charging-curve/).

```
(zumoPy) pi@pi:~ $ zumoPower
******************
Voltage: 4.23V
Battery:   98%
******************
Voltage: 4.23V
Battery:   98%
```

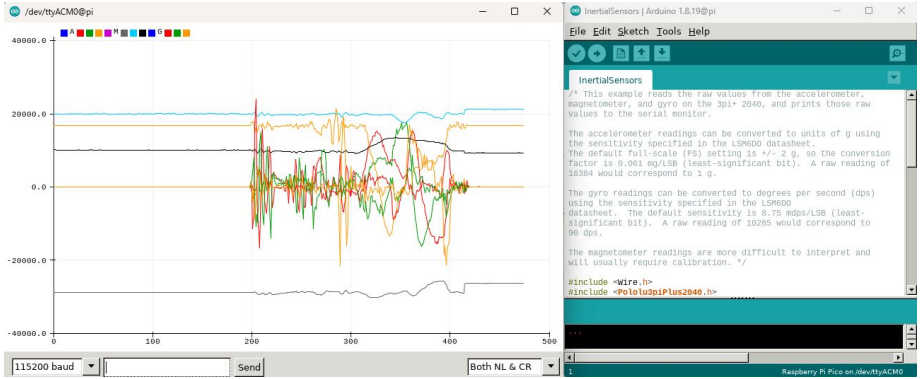


By: https://www.ufinebattery.com/blog/how-to-read-lithium-battery-discharge-curve-and-charging-curve/

Exercise 3 - Zumo Examples

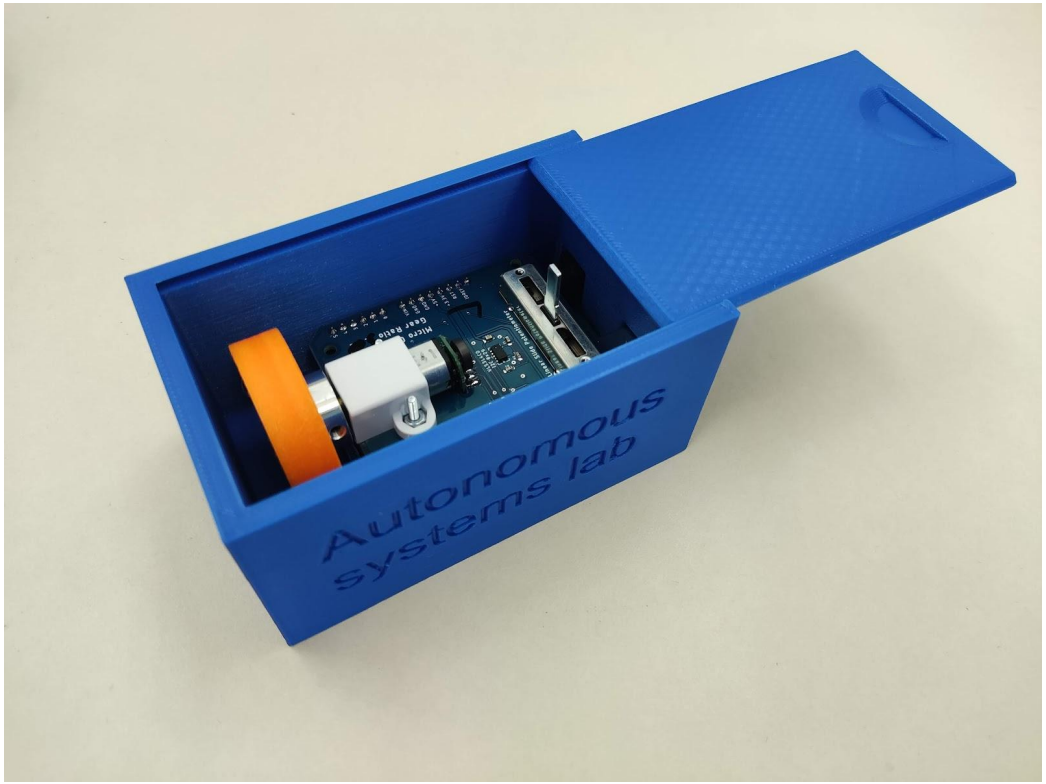


- Review the available examples for the zumo platform
  - Arduino examples under ~/WS_Zumo/Arduino/Examples
  - Python examples under ~/WS_Zumo/Python/Examples
- Turn off the system at the end of the session
  - Connect it to Power
  - Send shutdown command: sudo shutdown -h now
  - Turn off zumo platform using the power slider



Note: If you use Serial Plotter make sure to close it before uploading a new code

Home Kit Experiments



By: https://github.com/TALs-Education/HomeExperiments