

Lab #0: TurtleBot3 and Its Simple Control

Introduction

In this experiment, you will explore the capabilities of wheeled robots by controlling a **TurtleBot3 Waffle Pi**. You will also develop an understanding of the basic sensor data, coming from **camera**, **LiDAR** and **wheels encoders**.

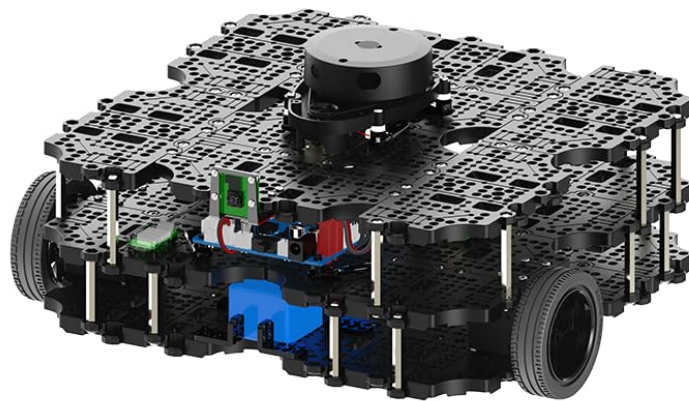


Figure 1: A TurtleBot3 Waffle Pi wheeled robot.

Getting Started

1. Connecting the Power to the Robot

1.1 Power via Adapter (SMPS)

While programming the **TurtleBot3 Waffle Pi**, it is recommended to power it through the AC/DC adapter (SMPS). Connect the adapter to the **OpenCR** board as shown in Figure 2.

1.2 Power via Battery Pack

When the robot is moving untethered, use the **Li-Po battery pack** supplied with TurtleBot3. Insert the battery cable into the **OpenCR power port** as shown in Figure 3.

2. Powering On the Robot

Locate the power switch on the **OpenCR Board** as shown in Figure 4 and switch it on.

Once the lights of the **OpenCR Board** and the **Raspberry Pi 4** start flickering, and the **LiDAR** starts spinning, wait for at least 30 seconds for the robot to boot.

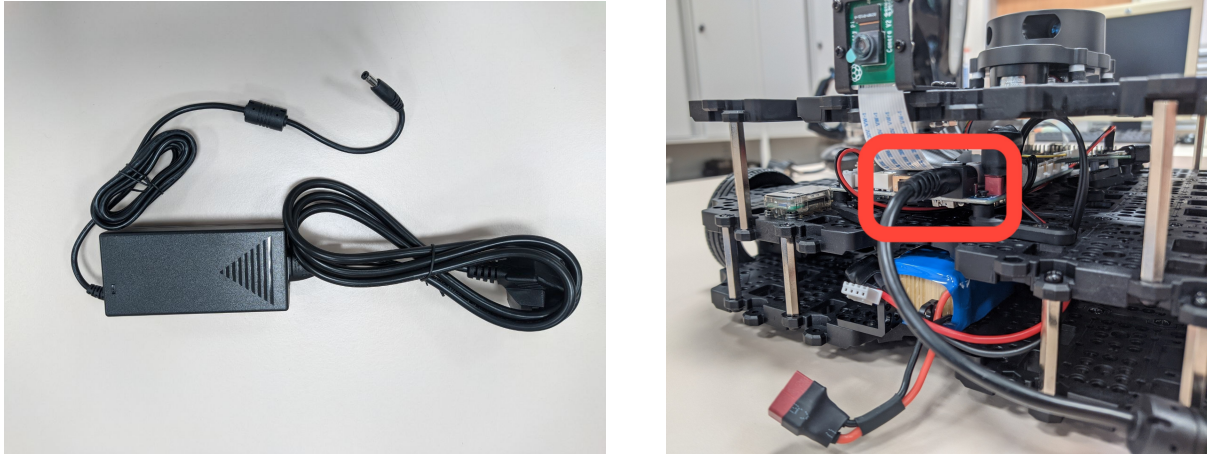


Figure 2: Connecting the SMPS to the OpenCR for tethered power.

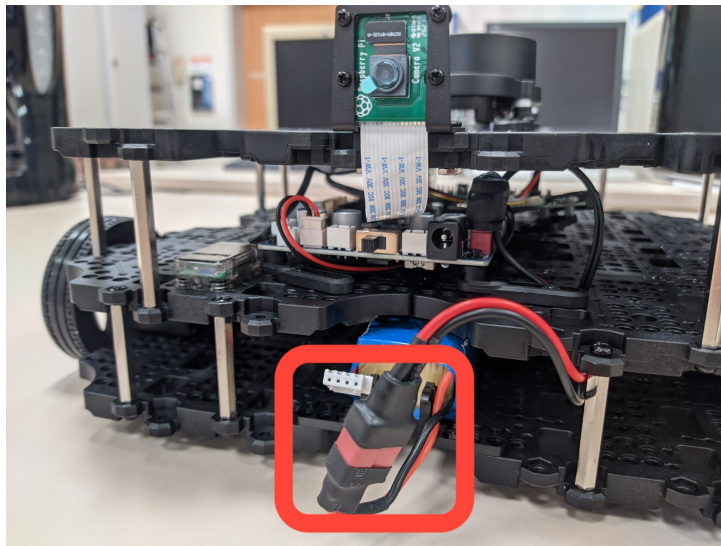


Figure 3: Connecting the battery pack for untethered power.

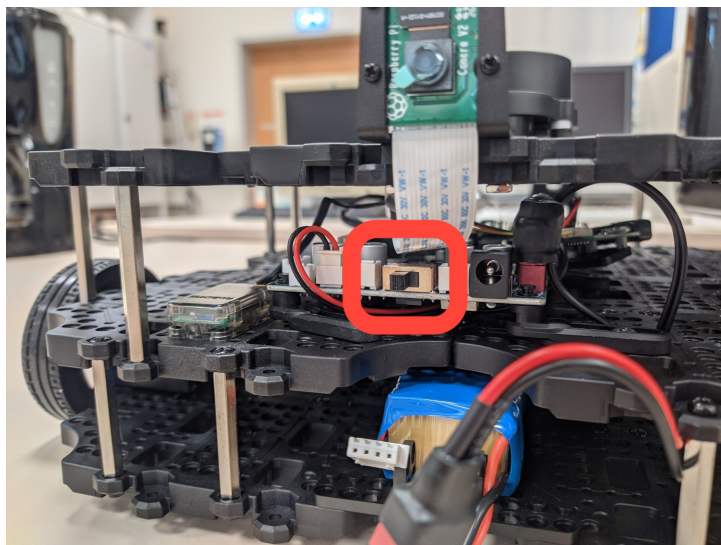


Figure 4: The power switch on the OpenCR Board.

3. Connecting the PC to the Robot

3.1 Wi-Fi Connection

For real-time autonomous operation, Wi-Fi is the preferred connection method. It allows the robot to move freely without cables, making it ideal for navigation and mapping tasks.

Wi-Fi Setup Steps:

- Connect your PC/Laptop to the **TurtleBot3 Waffle Pi**'s Wi-Fi hotspot:

Name: TBX
Password: 12345678

(Wi-Fi hotspot information is written on the **TurtleBot3's ID Card**)

Follow the steps shown in Figure 5.

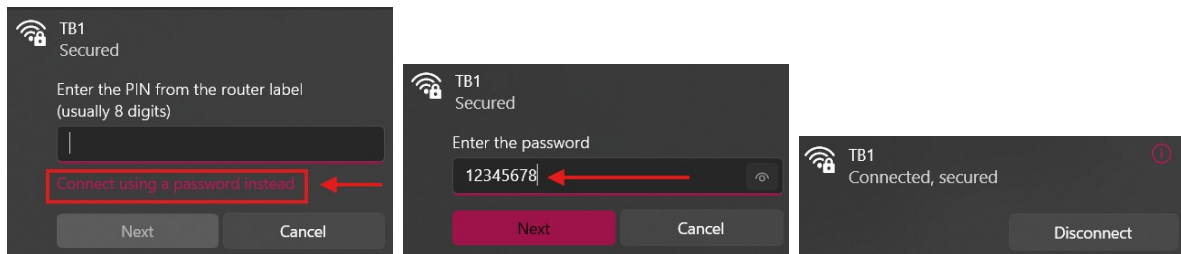


Figure 5: Connecting to the TurtleBot3 Wi-Fi hotspot.

- Open a **Command Prompt (cmd)** or **PowerShell** window on your PC by searching it from the Start menu.
- Test connectivity to the robot's Raspberry Pi by typing:

```
ping 192.168.XX.1
```

(Wi-Fi IP information is written on the **TurtleBot3's ID Card**)

- Open an SSH connection to the robot by typing:

```
ssh me425-1@192.168.XX.1
```

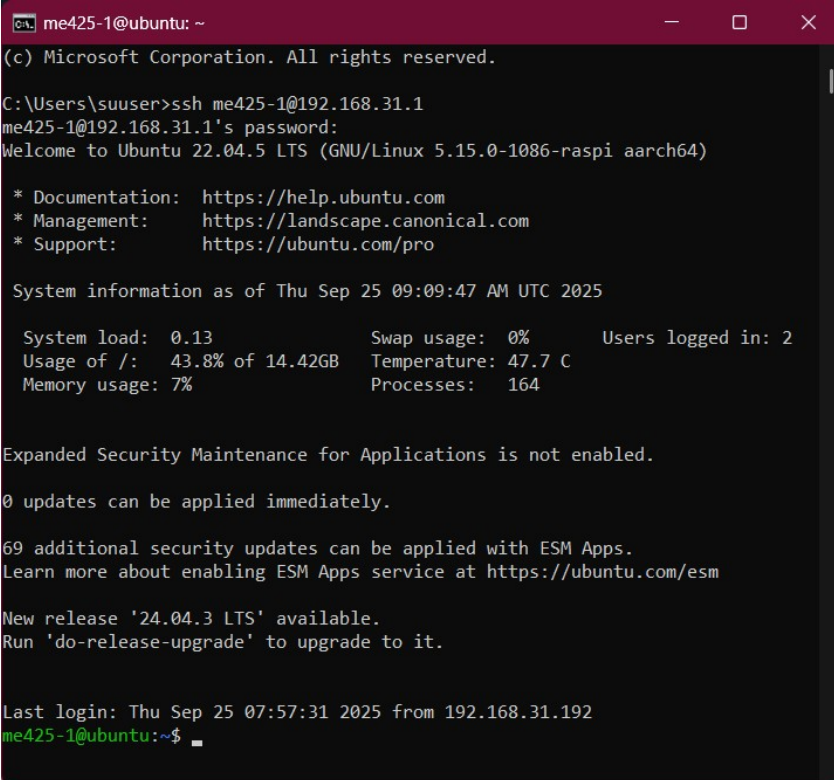
(Login Username and Wi-Fi IP information are written on the **TurtleBot3's ID Card**)

You will then be prompted to enter the password:

```
me425-1@192.168.XX.1's password:
```

(Password is 1234 for all the **TurtleBot3s**.)

- Once connected successfully, you should see a terminal similar to Figure 6.



```
me425-1@ubuntu: ~  
(c) Microsoft Corporation. All rights reserved.  
C:\Users\suser>ssh me425-1@192.168.31.1  
me425-1@192.168.31.1's password:  
Welcome to Ubuntu 22.04.5 LTS (GNU/Linux 5.15.0-1086-raspi aarch64)  
  
* Documentation:  https://help.ubuntu.com  
* Management:    https://landscape.canonical.com  
* Support:        https://ubuntu.com/pro  
  
System information as of Thu Sep 25 09:09:47 AM UTC 2025  
  
System load:  0.13           Swap usage:   0%           Users logged in: 2  
Usage of /:   43.8% of 14.42GB Temperature: 47.7 C  
Memory usage: 7%           Processes:    164  
  
Expanded Security Maintenance for Applications is not enabled.  
  
0 updates can be applied immediately.  
  
69 additional security updates can be applied with ESM Apps.  
Learn more about enabling ESM Apps service at https://ubuntu.com/esm  
  
New release '24.04.3 LTS' available.  
Run 'do-release-upgrade' to upgrade to it.  
  
Last login: Thu Sep 25 07:57:31 2025 from 192.168.31.192  
me425-1@ubuntu:~$
```

Figure 6: Successful SSH connection to the TurtleBot3 over Wi-Fi.

3.2 Ethernet Connection

Note

For now, you will not need to connect via Ethernet if you are already connected through Wi-Fi. Check appendix to see the full setup steps in case of Wi-Fi connection loss.

4. ROS Nodes Bring-up on the Robot

Once your connected robustly to the **TurtleBot3** via Wi-Fi or Ethernet, you can now control it via your ssh connection from the **Command Prompt (cmd)** or **PowerShell** on your PC. By default, no ROS nodes are running. You must launch the bring-up process to start publishing the required sensor data.

Bring-up Setup Steps:

- Connect your PC to the TurtleBot3 (either via Wi-Fi or Ethernet tethering) and make sure that you are seeing a terminal similar to Figure 6 or Figure 9.
- In the same **Command Prompt (cmd)** or **PowerShell** window you already have on your PC, launch the **TurtleBot3** bring-up node by typing:

```
bringup
```

- Once the bring-up is successful, you should see a terminal similar to Figure 7.


```

Select me425-1@ubuntu: ~
[v4l2_camera_node-4] [INFO] [1758787530.430986400] [v4l2_camera]: Repeat Sequence Header (2) = 0
[v4l2_camera_node-4] [ERROR] [1758787530.431024460] [v4l2_camera]: Failed getting value for control 10029541: Permission denied (13); returning 0!
[v4l2_camera_node-4] [INFO] [1758787530.431051919] [v4l2_camera]: Force Key Frame (4) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431088048] [v4l2_camera]: H264 Minimum QP Value (1) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431125993] [v4l2_camera]: H264 Maximum QP Value (1) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431162993] [v4l2_camera]: H264 I-Frame Period (1) = 60
[v4l2_camera_node-4] [INFO] [1758787530.431201048] [v4l2_camera]: H264 Level (3) = 11
[v4l2_camera_node-4] [INFO] [1758787530.431237882] [v4l2_camera]: H264 Profile (3) = 4
[v4l2_camera_node-4] [ERROR] [1758787530.431275956] [v4l2_camera]: Failed getting value for control 10092545: Permission denied (13); returning 0!
[v4l2_camera_node-4] [INFO] [1758787530.431302456] [v4l2_camera]: Camera Controls (6) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431339715] [v4l2_camera]: Auto Exposure (3) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431377974] [v4l2_camera]: Exposure Time, Absolute (1) = 1000
[v4l2_camera_node-4] [INFO] [1758787530.431415771] [v4l2_camera]: Exposure, Dynamic Framerate (2) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431455945] [v4l2_camera]: Auto Exposure, Bias (9) = 12
[v4l2_camera_node-4] [INFO] [1758787530.431493556] [v4l2_camera]: White Balance, Auto & Preset (3) = 1
[v4l2_camera_node-4] [INFO] [1758787530.431532168] [v4l2_camera]: Image Stabilization (2) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431570993] [v4l2_camera]: ISO Sensitivity (9) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431779660] [v4l2_camera]: ISO Sensitivity, Auto (3) = 1
[v4l2_camera_node-4] [INFO] [1758787530.431821067] [v4l2_camera]: Exposure, Metering Mode (3) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431863419] [v4l2_camera]: Scene Mode (3) = 0
[v4l2_camera_node-4] [ERROR] [1758787530.431905493] [v4l2_camera]: Failed getting value for control 10289153: Permission denied (13); returning 0!
[v4l2_camera_node-4] [INFO] [1758787530.431935660] [v4l2_camera]: JPEG Compression Controls (6) = 0
[v4l2_camera_node-4] [INFO] [1758787530.431970900] [v4l2_camera]: Compression Quality (3) = 10
[v4l2_camera_node-4] [WARN] [1758787530.434423456] [camera]: Control type not currently supported: 6, for control: Code Controls
[v4l2_camera_node-4] [WARN] [1758787530.435278771] [camera]: Control type not currently supported: 4, for control: Force Key Frame
[v4l2_camera_node-4] [WARN] [1758787530.435602845] [camera]: Control type not currently supported: 6, for control: Camera Controls
[v4l2_camera_node-4] [WARN] [1758787530.435801956] [camera]: Control type not currently supported: 9, for control: Auto Exposure, Bias
[v4l2_camera_node-4] [WARN] [1758787530.435985752] [camera]: Control type not currently supported: 9, for control: ISO Sensitivity
[v4l2_camera_node-4] [WARN] [1758787530.436264697] [camera]: Control type not currently supported: 6, for control: JPEG Compression Controls
[v4l2_camera_node-4] [INFO] [1758787530.436408063] [v4l2_camera]: Requesting format: 1024x768 YUVV
[v4l2_camera_node-4] [INFO] [1758787530.442683826] [v4l2_camera]: Success
[v4l2_camera_node-4] [INFO] [1758787530.442778184] [v4l2_camera]: Requesting format: 640x480 YUVV
[v4l2_camera_node-4] [INFO] [1758787530.443238280] [v4l2_camera]: Success
[v4l2_camera_node-4] [INFO] [1758787530.445423530] [v4l2_camera]: Starting camera
[v4l2_camera_node-4] [WARN] [1758787531.132785826] [camera]: Image encoding not the same as requested output, performing possibly slow conversion: yuv422_yuy2 -> rgb8
[v4l2_camera_node-4] [INFO] [1758787531.181741548] [camera]: Using default calibration URL
[v4l2_camera_node-4] [INFO] [1758787531.181348480] [camera]: camera calibration URL: file:///home/me425-1/.ros/camera_info/mmal_service_16.1.yaml
[v4l2_camera_node-4] [ERROR] [1758787531.182325789] [camera_calibration_parser]: Unable to open camera calibration file [/home/me425-1/.ros/camera_info/mmal_service_16.1.yaml]
[v4l2_camera_node-4] [WARN] [1758787531.182465104] [camera]: Camera calibration file: Unable to open camera calibration file [/home/me425-1/.ros/camera_info/mmal_service_16.1.yaml] not found
[v4l2_camera_node-4] [INFO] [1758787531.417741971] [turtlebot3_node]: Calibration End
[turtlebot3_ros-3] [INFO] [1758787533.417994528] [turtlebot3_node]: Add Motors
[turtlebot3_ros-3] [INFO] [1758787533.418643695] [turtlebot3_node]: Add wheels
[turtlebot3_ros-3] [INFO] [1758787533.419676521] [turtlebot3_node]: Add Sensors
[turtlebot3_ros-3] [INFO] [1758787533.443921917] [turtlebot3_node]: Succeeded to create battery state publisher
[turtlebot3_ros-3] [INFO] [1758787533.449331380] [turtlebot3_node]: Succeeded to create imu publisher
[turtlebot3_ros-3] [INFO] [1758787533.466765223] [turtlebot3_node]: Succeeded to create sensor state publisher
[turtlebot3_ros-3] [INFO] [1758787533.480372213] [turtlebot3_node]: Succeeded to create joint state publisher
[turtlebot3_ros-3] [INFO] [1758787533.480468639] [turtlebot3_node]: Add Devices
[turtlebot3_ros-3] [INFO] [1758787533.480514398] [turtlebot3_node]: Succeeded to create motor power server
[turtlebot3_ros-3] [INFO] [1758787533.493295454] [turtlebot3_node]: Succeeded to create reset server
[turtlebot3_ros-3] [INFO] [1758787533.496819158] [turtlebot3_node]: Succeeded to create sound server
[turtlebot3_ros-3] [INFO] [1758787533.500526158] [turtlebot3_node]: Run!
[turtlebot3_ros-3] [INFO] [1758787533.572041065] [diff_drive_controller]: Init Odometry
[turtlebot3_ros-3] [INFO] [1758787533.600497158] [diff_drive_controller]: Run!

```

Figure 7: Successful launch of the bring-up node.

- Leave this terminal window open and running. You are now ready to continue with MATLAB!

5. MATLAB Setup for TurtleBot3

Before running any MATLAB code, configure your ROS 2 environment to match the TurtleBot3's Raspberry Pi.

MATLAB Preparation Steps:

- Add this block at the beginning of any MATLAB script:

```

%% --- MATLAB TurtleBot3 ROS 2 setup ---
clear node; % clear previous node handle if it exists
setenv('ROS_DOMAIN_ID','XX'); % Set to your robots ROS_DOMAIN_ID
setenv('ROS_LOCALHOST_ONLY','0'); % Must be 0 for multi-host
communication
setenv('RMW_IMPLEMENTATION','rmw_fastrtps_cpp'); % Middleware

% Create a unique node name for this MATLAB session
node = ros2node('ANY_NAME_YOU_WANT');

```

(ROS Domain ID is written on the TurtleBot3's ID Card)

- *Optional:* Check your environment and node:

```

% --- Quick sanity check: display the node name and current environment
---
disp("ROS 2 up. Node: " + node.Name);
disp("ROS_DOMAIN_ID = " + string(getenv('ROS_DOMAIN_ID')));
disp("RMW_IMPLEMENTATION = " + string(getenv('RMW_IMPLEMENTATION')));

```

- *Optional:* Verify ROS traffic from the robot:

```
% Create a lightweight /scan subscriber to confirm traffic:
subScan = ros2subscriber(node, "/scan", "sensor_msgs/LaserScan", ...
    "Reliability", "besteffort", "Durability", "volatile", "Depth", 10);

msg = receive(subScan, 5); % Set waiting time in seconds

if isempty(msg)
    disp("Waiting for /scan... (Start the bringup on the robot from the
        cmd!)")
end
```

Important Note

Never power off the **TurtleBot3** using the power switch located on the **OpenCR Board** shown in Figure 4! (this will cause the system to be corrupted)

The proper way is by typing:

```
sudo poweroff
```

into the already running cmd terminal shown in Figure 6 or Figure 9.

If your ROS nodes are up and running like in Figure 7, you will first need to stop them by pressing **CTRL + C** inside the cmd terminal, then you can power off the system using:

```
sudo poweroff
```

once the LiDAR stops spinning, this indicates that the robot is safely shut down, so now you can turn off the switch shown in Figure 4 and disconnect the battery or SMPS.

The Experiment

Goals

- Use onboard sensors: **LiDAR**, **camera**, and **wheel encoders**.
- Visualize sensor streams in MATLAB.
- Command the robot to execute **forward**, **backward**, and **circular** motions at different speeds.
- Record and plot **encoder** data for each maneuver.

Checklist Before You Start

- You are connected to the robot via **Wi-Fi or Ethernet** (only one at a time).
- You can SSH into the robot and have launched bringup on the robot.
- MATLAB ROS 2 environment is configured.

Part A — Sensor Bringup & Visualization

Implement `cameraLidar.m` to:

1. Subscribe to the LiDAR topic (`/scan`, `sensor_msgs/LaserScan`).
2. Subscribe to the camera topic (`/image_raw/compressed`, `sensor_msgs/CompressedImage`).
3. Display a camera view and a simple LiDAR visualization (e.g., polar plot or range vs. index).
4. Take a screen-shot of the output (image and LiDAR plot) at specific instance.

Part B — Simple Open Loop Motion Control & Encoders

Implement `controlledMotion.m` to:

1. Publish velocity commands on `/cmd_vel` (`geometry_msgs/Twist`) to move:
 - Forward for 3–5 s,
 - Backward for 3–5 s,
 - Circle: send nonzero angular velocity for 8–12 s.
2. Subscribe to `/joint_states` (`sensor_msgs/JointState`) and log left/right wheel positions (ticks/ radians).
3. Plot both wheel encoder traces vs. time for each maneuver and comment on symmetry/offsets.

Safety: Lift the robot wheels or keep a clear area when testing `/cmd_vel`.

Things to do:

- Submit your report **via SUCourse** until the report submission deadline.

Post-Lab Report Deadline: 15 October 2025, 23:55 via **SUCourse**

- Your report must include:
 - **Introduction**
 - **Procedure**
 - **Results**
 - **Conclusion**
 - **Discussion**
 - **Appendix**
 - Provide your **MATLAB** codes in Appendix section appropriately.

Answer the following questions in the Discussion section of your Post-lab report:

- Plot the data that you obtained from LiDAR. How do you think these data are related to the surrounding environment?
- Take a screen shot of your camera output. Comment on how you think camera is used in autonomous mobile robotics.
- Can your robot move straight and rotate properly? Plot the encoder values of both motors to clarify your answer.

Appendix: Ethernet Connection (if needed)

Ethernet Setup Steps:

For a more stable and faster connection, connect the robot directly to your PC/Laptop using an Ethernet cable.

- Connect one end of the Ethernet cable to your PC/Laptop and the other end to the **Raspberry Pi 4** on the TurtleBot3.
- Set up your PC's Ethernet settings as shown in Figure 8.

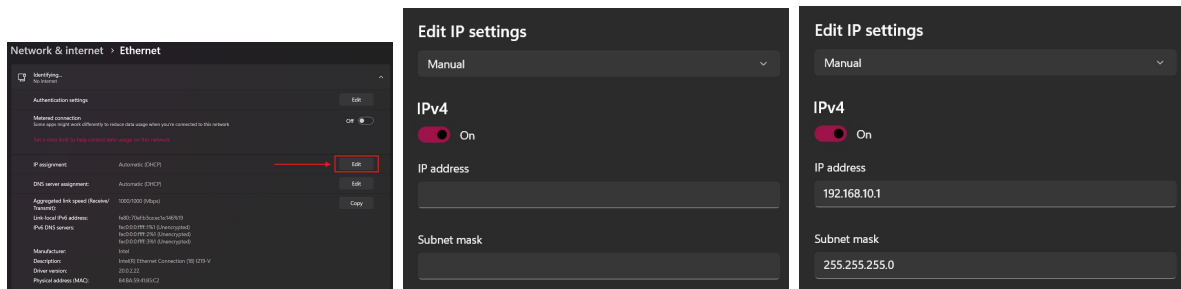


Figure 8: Setting up PC's Ethernet IP address

- Then your PC will automatically detect the connection. The robot will use the IP address:

```
192.168.10.2
```

(Same Ethernet IP for all the **TurtleBot3s**)

- Open a **Command Prompt (cmd)** or **PowerShell** window on your PC by searching it from the Start menu.
- Test connectivity to the robot's Raspberry Pi by typing:

```
ping 192.168.10.2
```

(Same Ethernet IP for all the **TurtleBot3s**)

- Open an SSH connection to the robot by typing:

```
ssh me425-1@192.168.10.2
```

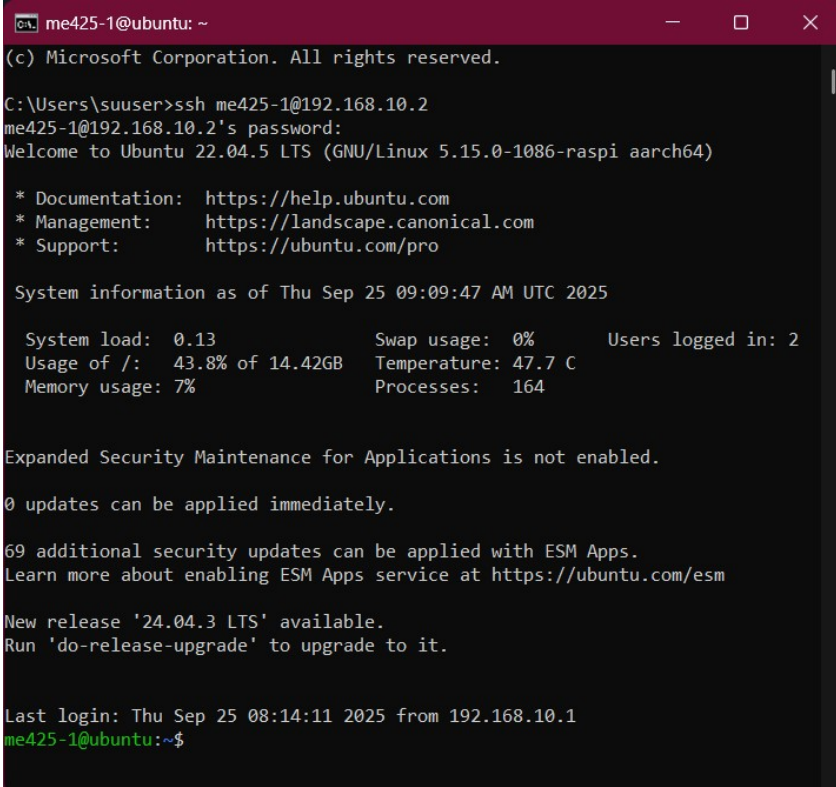
(Same Login Username and Ethernet IP for all the **TurtleBot3s**)

You will then be prompted to enter the password:

```
me425-1@192.168.10.2's password:
```

(Password is 1234 for all the **TurtleBot3s**.)

- Once connected successfully, you should see a terminal similar to Figure 9.



```
me425-1@ubuntu: ~  
(c) Microsoft Corporation. All rights reserved.  
C:\Users\suser>ssh me425-1@192.168.10.2  
me425-1@192.168.10.2's password:  
Welcome to Ubuntu 22.04.5 LTS (GNU/Linux 5.15.0-1086-raspi aarch64)  
  
* Documentation:  https://help.ubuntu.com  
* Management:    https://landscape.canonical.com  
* Support:       https://ubuntu.com/pro  
  
System information as of Thu Sep 25 09:09:47 AM UTC 2025  
  
System load:  0.13           Swap usage:   0%           Users logged in: 2  
Usage of /:   43.8% of 14.42GB Temperature: 47.7 C  
Memory usage: 7%           Processes:   164  
  
Expanded Security Maintenance for Applications is not enabled.  
  
0 updates can be applied immediately.  
  
69 additional security updates can be applied with ESM Apps.  
Learn more about enabling ESM Apps service at https://ubuntu.com/esm  
  
New release '24.04.3 LTS' available.  
Run 'do-release-upgrade' to upgrade to it.  
  
Last login: Thu Sep 25 08:14:11 2025 from 192.168.10.1  
me425-1@ubuntu:~$
```

Figure 9: Successful SSH connection to the TurtleBot3 over Ethernet.

Important Note

Only use **one connection method at a time** (either Wi-Fi *or* Ethernet). Having both connected simultaneously to your PC will cause conflicts in MATLAB and lead to communication errors.