LABORATORY GUIDE

AUTONOMOUS SYSTEMS

Alberto Vale, João Luzio, Kevin Alcedo, Marcelo Jacinto, Paulo Nogueira,
Rui Xavier, Rodrigo Ventura, Luís Custódio

2024/2025

PRE-REQUISITES: Personal laptop

- **Ubuntu** 20.04 LTS (recommended) (ROS1 is not supported in 22.04LTS)
- **Windows or MacOS**:
    1. Dual boot (with one of the Ubuntu versions mention above; not recommended in **MacOS** since is not officially supported in Apple Silicon)
    2. Virtual machine with at least 4GB of RAM and 20GB of space: **VMware** recommended*, **Parallels**, or **UTM** (not so fast, but with graphical environment)
    3. **WSL** 1 or 2 (2 recommended) + X Server (VcXsrv recommended)**
    4. Lightweight virtual machine: **Multipass** (fast but no graphical environment; use foxglove for visualization)
    5. Using ROS 1 directly on Windows 10 is not recommended
    6. Using Docker and ROS 1 image not recommended (unless you are already familiar with it)

* Check https://si.tecnico.ulisboa.pt/software/vmware/ for free student license.VirtualBox can also be used, but not recommended.

** Disable access control and add to the .bashrc the following line: “export DISPLAY=<hostname>.local:0”

PRE-REQUISITES: Laboratory computers

- Ubuntu with ROS 1 pre-installed
- Computers are connected to the deec-robots network

  (the same as all robots)
  - Username: acsdc
  - Password: acsdclsdc4

INSTALLING LINUX AND ROS 1

TÉCNICO LISBOA

- Each ROS 1 version is linked to an Ubuntu LTS release

Operating System	ROS 1 Version	Python Version
Ubuntu 16.04LTS	ROS Kinetic	2
Ubuntu 18.04LTS	ROS Melodic	2
Ubuntu 20.04LTS (recommended)	ROS Noetic	3
Ubuntu 22.04LTS	Not Supported	---

- Desktop-Full Install is recommended
- If you have troubles with the official ROS Noetic installation, follow these instructions (https://varhowto.com/install-ros-noetic-ubuntu-20-04)

RECOMMENDATIONS

1. USE TERMINATOR

- On the laptop, run

```
sudo apt-get install terminator
```

Tips and Tricks

```
ctrl + shift + C (copy)
ctrl + shift + V (paste or use the right button of mouse)
ctrl + shift + O (split the terminal horizontally)
ctrl + shift + E (split the terminal vertically)
ctrl + shift + Z (focus/unfocus a terminal window)
```

2. DEVELOP YOUR PROJECT IN PYTHON

GETTING STARTED WITH ROS

- "Introduction to the Robot Operating System (ROS)", from Rodrigo Ventura
  [mandatory if the first contact with ROS]
- Short course videos from Rodrigo Ventura and João Avelino **[complementary]**
  - Part 1: https://www.youtube.com/watch?v=3aVYUAj7sr4&t=1205s&ab_channel=RodrigoVentura
  - Part 2: https://www.youtube.com/watch?v=zqpKWHHlgOA&ab_channel=RodrigoVentura

THE LABORATORY

- Located at the 5th floor of the North Tower – Room LSDC4

WIFI (Pioneers, Alphabots and Turtlebots):

Network: deec-robots

Password: shakeytherobot

IP range: 192.168.28.<id>

Lab computers:

Username: acsdc

Password: acsdclsdc4

THE LAB COMPUTERS

- Lab computers shall be used **to test code** or **to record bag files** and **NOT for development**.
- Check the Wi-Fi connection of the lab computers to deec-robots network (if not working properly, please contact Mr. Manuel Ribeiro (office 5.18, mribeiro@tecnico.ulisboa.pt, phone number 2189 inside Técnico, 218418189 from outside).
- ROS_HOSTNAME AND ROS_IP have been added as an alias in the lab computers, they can also be exported by simply running EXPORT_HOST.
  These export commands are needed in each new terminal that will use ROS to communicate with the robot.

THE PIONEER ROBOTS

- The Pioneer robots are configured with:
  1. A Raspberry Pi with Ubuntu 18.04LTS and ROS 1 Melodic
  2. The P2OS ROS package

- Relevant topic of P2OS node:
  - Subscribes:
    - **/cmd_vel** (geometry_msgs/Twist)
  - Publishes:
    - **/pose** (nav_msgs/Odometry)
    - **/sonar** (p2os_driver/SonarArray)
- Hokuyo laser rangefinder:
  - Publishes:
    - **/scan** (sensor_msgs/LaserScan)

CREDENTIALS:

Username: pi

Password: acsdclsdc4

Network: deec-robots

Password: shakeytherobot

IP range: 192.168.28.[17…23]

THE PIONEER ROBOTS [Connecting]

1. On a new terminal of the Laptop/Lab computer, and SSH into the RPi of the **Pioneer**

```
ssh pi@192.168.28.[17…23]
```

2. Start a roscore instance inside the RPi of the **Pioneer**

```
roscore
```

3. Open another terminal in the Laptop/Lab computer and SSH into the RPi again

```
ssh pi@192.168.28.[17…23]
rosrun p2os_driver p2os_driver _port:="/dev/ttyUSB0"      (or)
rosrun p2os_driver p2os_driver _port:="/dev/ttyUSB0" _use_sonar:="true"
```

4. Run in the Laptop/Lab computer (or append to you ~/.bashrc file)

```
export ROS_MASTER_URI=http://192.168.28.[17…23]:11311  [Pioneer/RPi IP]
export ROS_HOSTNAME=192.168.[27/28].XXX  [Lab computer IP/Laptop]
export ROS_IP=192.168.[27/28].XXX  [Lab computer IP/Laptop]
```

If `ipconfig` is not available, use `ip address` or install net-tools to run `ifconfig`:

```
apt update
apt install net-tools
```

THE PIONEER ROBOTS [Communications]

TÉCNICO LISBOA

5. Test the communications: can the computer see the robot's topics?

```
rostopic list
```

6. Interesting topics to query: "/pose", "/sonar"

```
rostopic echo "/pose"
rostopic info "/pose"
rostopic hz "/pose"
```

7. Test motion commands *

```
rostopic pub /cmd_vel geometry_msgs/Twist '[0.0, 0.0, 0.0]' '[0.0, 0.0, 0.5]' (or)
rostopic pub -r 1 /cmd_vel geometry_msgs/Twist '[0.1, 0.0, 0.0]' '[0.0, 0.0, 0.0]'
```

8. To record topics in rosbags **

```
rosbag record -a (for all topics)
rosbag record /<topic name> (for specific topics)
```

* Check that the motors are enabled, the topic `/motor_state` should be 1. If not, press the 'motors' button on the robot. Press again to stop!

** If path unspecified, bags get recorded in the folder where the command is run. See http://wiki.ros.org/rosbag/Commandline#record

THE PIONEER ROBOTS [Operation]

9. Install the teleop package - run in the laptop once **[skip for lab computers]**

```
sudo apt-get install ros-noetic-teleop-twist-keyboard
```

10. Control the robot. On the laptop/Lab computer, run

```
rosrun teleop_twist_keyboard teleop_twist_keyboard.py
```

THE PIONEER ROBOTS [Hokuyo rangefinder]

1. To install on your laptop (alternatively connect directly to the RPi on the robot, and skip this step)

```
sudo apt-get install ros-noetic-urg-node
```

2. Connect the Hokuyo and run

```
chmod a+rw /dev/ttyACM0
```

3. Launch the **urg** node on the device you connected the hokuyo (roscore is assumed to be running)

```
rosrun urg_node urg_node /dev/ttyACM0
```

4. To test with the RVIZ, run on the laptop/Lab computer the following command and see next slide (it is assumed that step 4 from slide 8 was executed)

```
rosrun rviz rviz
```

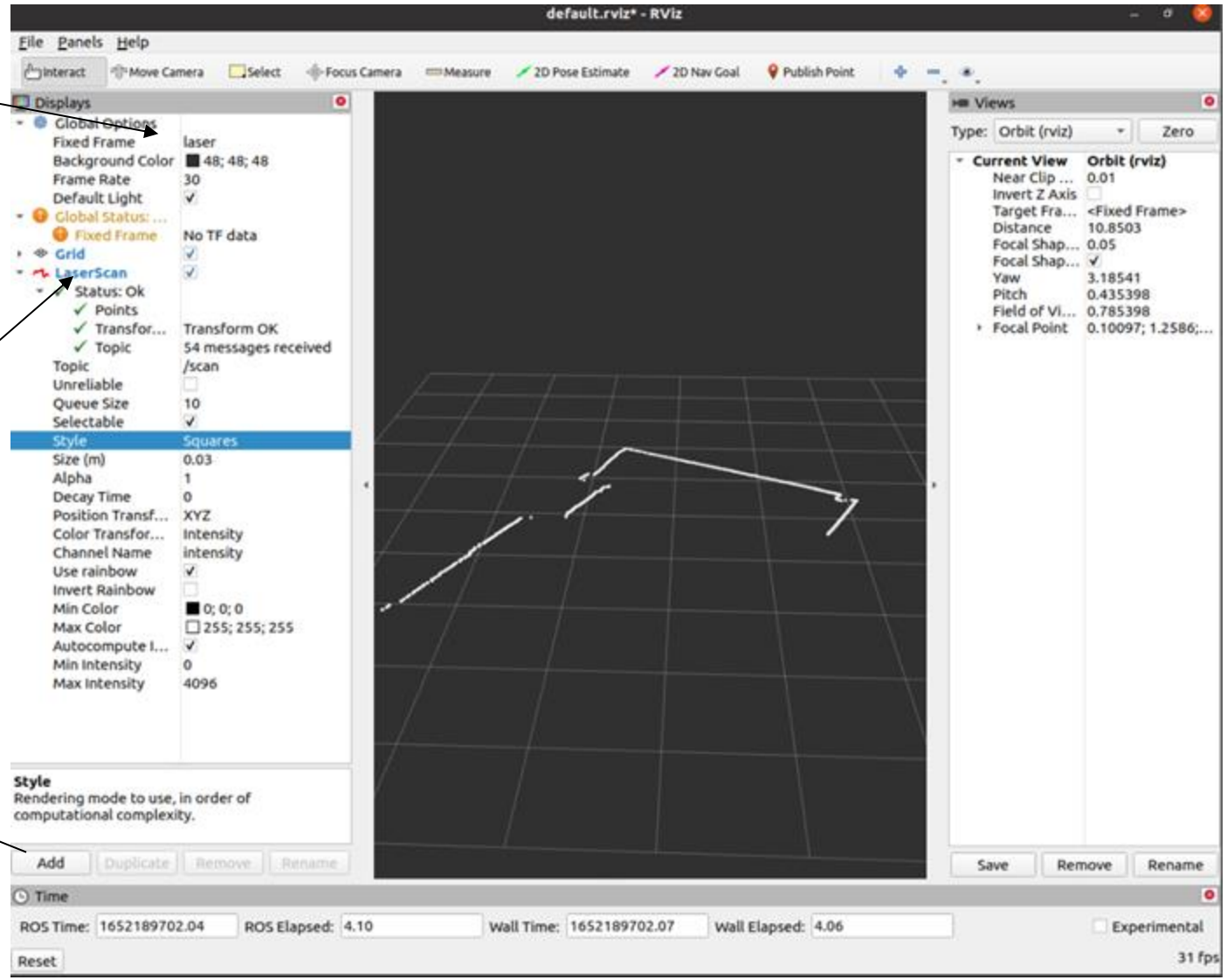
Request access to
Mr. Manuel Ribeiro

See http://wiki.ros.org/urg_node

THE PIONEER ROBOTS [Hokuyo rangefinder]

Write “laser”, since no referential was defined.

Add “LaserScan” node



THE PIONEER ROBOTS [Microsoft Kinect]

1. To use the Microsoft Kinect with the Pioneer robots, you must install a few packages on your laptop. Please follow these steps to install them:

```
sudo apt-get update
sudo apt-get upgrade
sudo apt-get install git-core cmake freeglut3-dev pkg-config build-
essential libxmu-dev libxi-dev libusb-1.0-0-dev

cd ~/src
git clone https://github.com/OpenKinect/libfreenect.git
cd libfreenect
mkdir build
cd build
cmake -L ..
Make
sudo make install
sudo ldconfig /usr/local/lib64/

cd ~/catkin_ws/src
git clone https://github.com/ros-drivers/freenect_stack.git
cd ..
catkin buildsource ~/catkin_ws/devel/setup.bash
```

Request access to
Mr. Manuel Ribeiro

THE PIONEER ROBOTS [Microsoft Kinect]

2. To run the node that publishes the images coming from the Kinect, you must first run this command on a terminal, after connecting the USB to your computer and the Kinect to the power outlet or the robots:

```
dmesg
```

3. One of the few last lines will contain similar information to this (check the device number and serial number). In this case, the USB device number is 21.

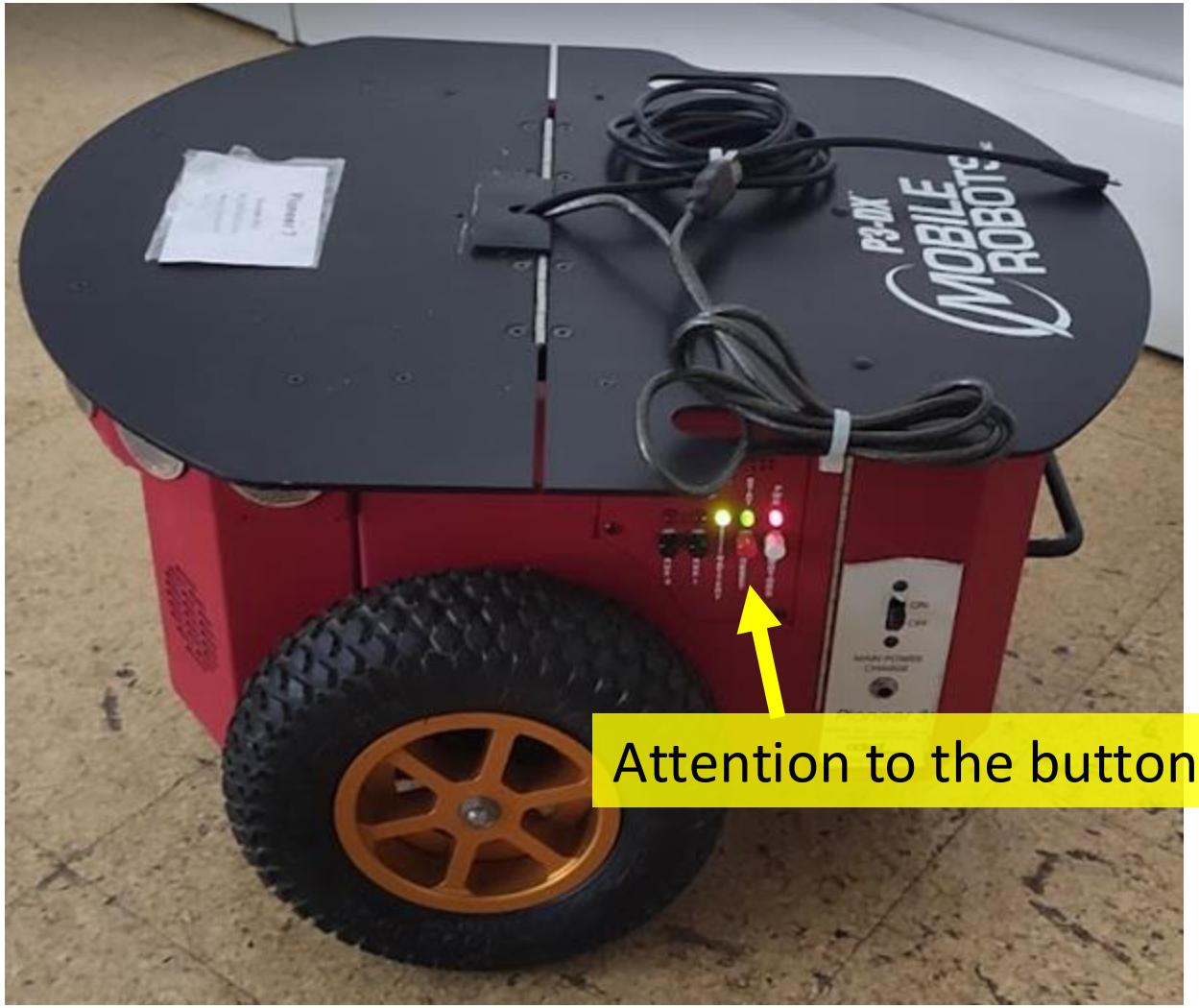
```
[11151.635280] usb 1-2.2: new full-speed USB device number 21 using xhci_hcd
```

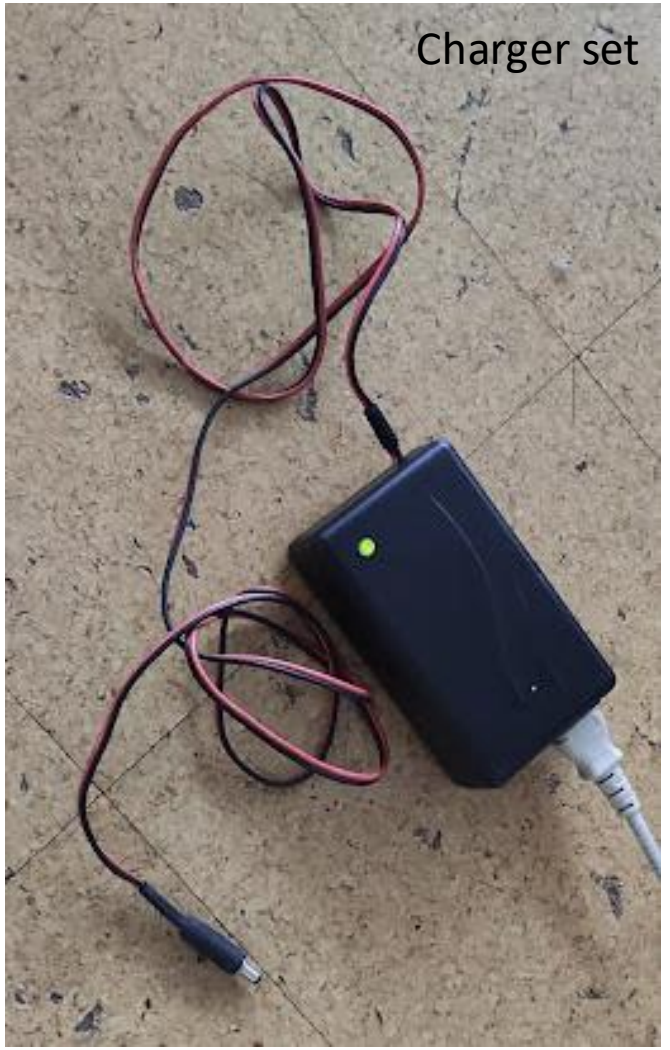
4. Now, launch the camera node using this command (replace the *device_id* by the number you got from the **dmesg** command):

```
roslaunch freenect_launch freenect.launch device_id:=21 depth_processing:=false
```

NOTE: If for some reason you can't still see the image from the camera in your computer, then try to replace the device_id by the serial number also shown in **dmesg**.

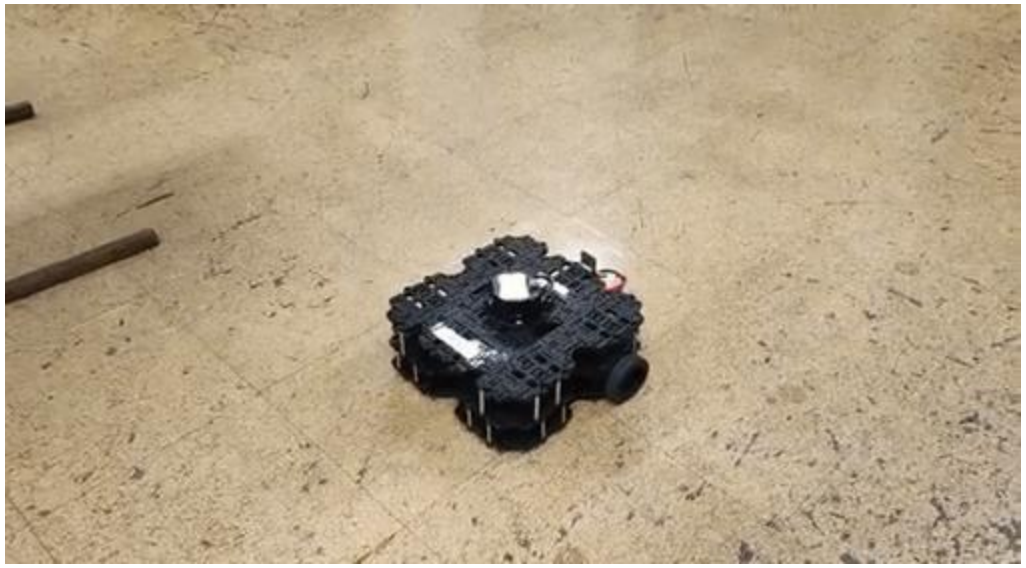
THE PIONEER ROBOTS [Charging]





THE TURTLEBOT ROBOTS

- The Turtlebots are configured with a Raspberry Pi with Ubuntu 18.04LTS and ROS 1 Melodic
- Relevant topics:
  - Subscribes:
    - **/cmd_vel** (geometry_msgs/Twist)
    - **/reset** (std_msgs/Empty)
  - Publishes:
    - **/odom** (nav_msgs/Odometry)
    - **/tf** (tf2_msgs/tfMessage)
    - **/scan** (sensor_msgs/LaserScan)
- Additional resources:
  - http://wiki.ros.org/turtlebot3_bringup
  - http://wiki.ros.org/hls_lfcd_lds_driver
  - http://wiki.ros.org/sensor_msgs/Tutorials



CREDENTIALS:

Username: user

Password: user

Network: deec-robots

Password: shakeytherobot

IP range: 192.168.28.[11…15]

THE TURTLEBOT ROBOTS [Connecting]

1. On a new terminal of the Laptop/Lab computer, and SSH into the RPi of the **Turtlebot**

```
ssh user@192.168.28.[11…15]
```

2. Start a roscore instance inside the RPi of the **Turtlebot**

```
roscore
```

3. Open another terminal in the Laptop/Lab computer and SSH into the RPi again

```
ssh user@192.168.28.[11…15]
```

4. Sync the robot time **[not mandatory]**

```
sudo apt-get install ntpdate
sudo ntpdate ntp.ubuntu.com
```

5. Launch the robot drivers

```
roslaunch turtlebot3_bringup turtlebot3_robot.launch
```

THE TURTLEBOT ROBOTS [Laptop Setup]

6. Install the Turtlebot3 packages - run in the laptop once **[skip for lab computers]**.

```
sudo apt-get install ros-noetic-dynamixel-sdk
sudo apt-get install ros-noetic-turtlebot3-msgs
sudo apt-get install ros-noetic-turtlebot3
sudo apt-get install ros-noetic-teleop-twist-keyboard
```

If `ipconfig` is not available, use `ip address` or install net-tools to run `ifconfig`:

```
apt update
apt install net-tools
```

7. Additional configurations. Run in the Laptop/Lab computer (or append to you ~/.bashrc file)

```
export TURTLEBOT3_MODEL=waffle_pi
export TURTLEBOT3_NAME=waffle4                          [TurtleBot3 191919 on the stick]
export TURTLEBOT3_IP=192.168.28.[11…15]                 [TurtleBot IP]
export TURTLEBOT3_NUMBER=[11…15]                        [Last numbers of the TurtleBot3 IP]
export ROS_MASTER_URI=http://192.168.28.[11…15]:11311   [TurtleBot3 IP]
export ROS_HOSTNAME=192.168.[27/28].XXX                 [lab computer / laptop IP]
export ROS_IP=192.168.[27/28].XXX                       [lab computer / laptop IP]
```

THE TURTLEBOT ROBOTS [Communications]

TÉCNICO LISBOA

8. Test the communications: can the computer see the robot's topics?

```
rostopic list
```

9. Interesting topics to query: "/odom", "/scan"

```
rostopic echo "/odom"
rostopic info "/odom"
rostopic hz "/odom"
```

10. Test motion commands

```
rostopic pub /cmd_vel geometry_msgs/Twist '[0.0, 0.0, 0.0]' '[0.0, 0.0, 0.5]' (or)
rostopic pub -r 1 /cmd_vel geometry_msgs/Twist '[0.1, 0.0, 0.0]' '[0.0, 0.0, 0.0]'
```

11. To record topics in rosbags *

```
rosbag record -a (for all topics)
rosbag record /<topic name> (for specific topics)
```

* If path unspecified, bags get recorded in the folder where the command is run. See http://wiki.ros.org/rosbag/Commandline#record

THE TURTLEBOT ROBOTS [Operation]

12. Control the robot. On the laptop/Lab computer, run

```
roslaunch turtlebot3_teleop turtlebot3_teleop_key.launch
```

Accessing the robot camera

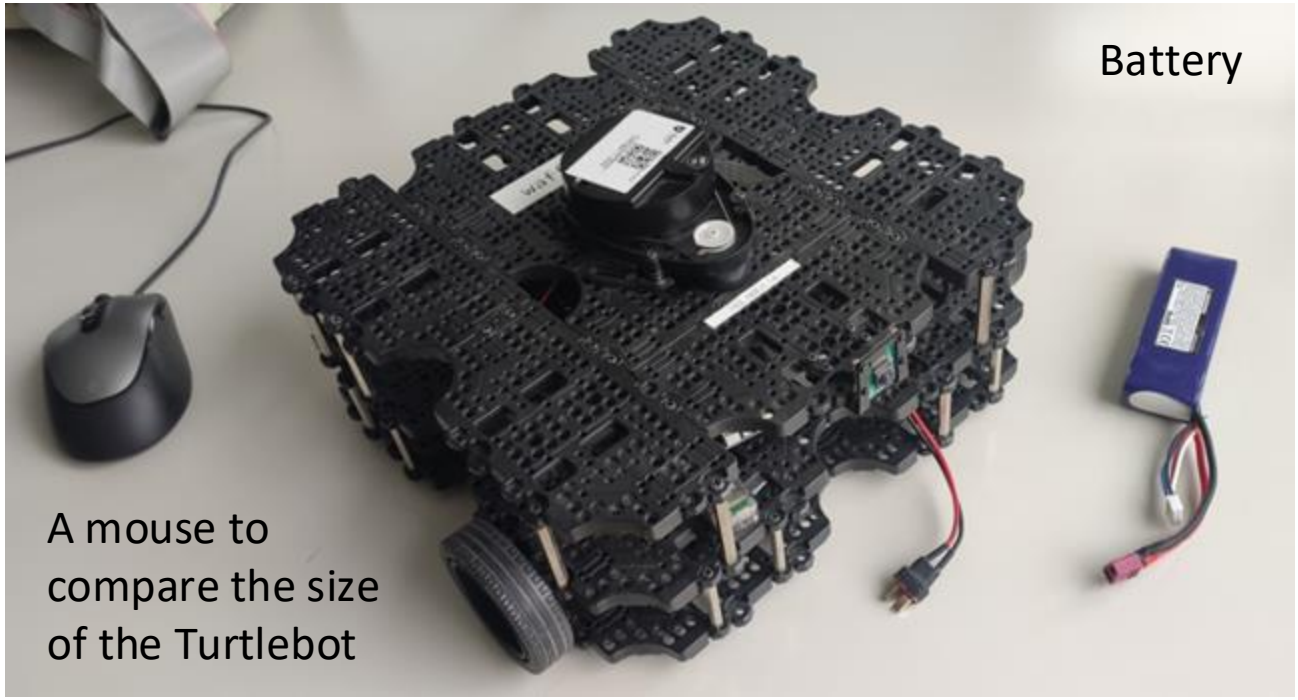
1. Launch the camera node on the robot

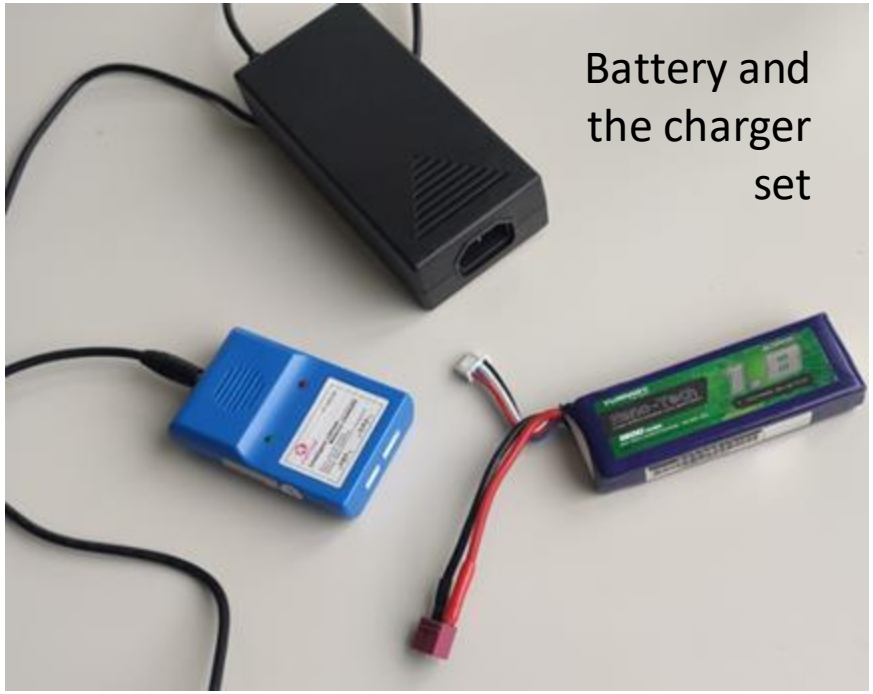
```
roslaunch turtlebot3_bringup turtlebot3_rpicamera.launch
```

2. To see the camera feed, run on the laptop/Lab computer

```
rosrun rqt_image_view rqt_image_view
```

THE TURTLEBOT ROBOTS [Charging]





THE ALPHABOT ROBOTS

- The Alphabots are configured with a Raspberry Pi 3 B, Ubuntu 20.04 LTS and ROS 1 Noetic
- Relevant topics:
  - Subscribes:
    - **/cmd_vel** (geometry_msgs/Twist)
  - Publishes:
    - **/camera/compressed** (sensor_msgs/CompressedImage)
- Additional resources:
  - ROS & Python drivers
  - Raspicam node
  - Fiducial slam
  - ROS for waveshare Alphabot2 (deprecated)

CREDENTIALS:

Username: alphabot2

Password: alphabot2

Network: deec-robots

Password: shakeytherobot

IP range: 192.168.28.[50…70]

Warning

These robots do NOT have wheel odometry, IMU or LiDAR

THE ALPHABOT ROBOTS [Operation]

1. Open a terminal on a Laptop/Lab computer, and SSH into the RPi of the **Alphabot**

```
ssh alphabot2@192.168.28.[50…70]
```

2. Initialize motion drivers (motor drive & camera servos)

```
cd ~/catkin_ws
source devel/setup.bash
roslaunch web_control web_control.launch
```

3. Open a web browser in the Laptop/Lab computer and go to the **`web_control`** link:

```
https://[192.168.28.[50…70]:8000/
```

4. Test motion control directly from the browser!

THE ALPHABOT ROBOTS [Camera]

1. Open a terminal on a Laptop/Lab computer, and SSH into the RPi of the **Alphabot**

```
ssh alphabot2@192.168.28.[50…70]
```

2. Launch the camera

```
source ~/catkin_ws/devel/setup.bash
roslaunch raspicam_node camerav2_1280x960.launch
```

3. Open a new terminal using X11 on a Laptop/Lab computer, and SSH into the RPi of the **Alphabot**

```
ssh -X alphabot2@192.168.28.[50…70]
```

4. Visualize the camera stream

```
rqt_image_view
```

THE ALPHABOT ROBOTS [Camera]

5. (Alternate) Rviz cannot handle compressed images, but if you prefer Rviz to visualize images, it is necessary the following in your laptop and subscribe the topic /raspicam_node/image_raw:

```
sudo apt-get install ros-noetic-image-transport

rosrun image_transport republish compressed in:=/raspicam_node/image raw out:=/raspicam_no/image_raw
```

6. (Alternate) Try out foxglove! (https://foxglove.dev/)

To learn more about the Alphabot drivers: https://github.com/Kons-5/ROS-for-the-Alphabot2

Make sure to checkout the repo's wiki for more details (i.e. camera calibration, Aruco detection, etc.)

Consider contributing this "home-grown" open-source project throughout the course 😎

THE ALPHABOT ROBOTS [Communications]

7. Run in the Laptop/Lab computer (or append to you ~/.bashrc file)

```
export ROS_MASTER_URI=http://192.168.28.[50…70]:11311      [Alphabot-RPi IP]
export ROS_HOSTNAME=192.168.28.XXX                         [Lab computer IP/Laptop]
export ROS_IP=192.168.28.XXX                               [Lab computer IP/Laptop]
```

8. Test the communications: can the computer see the robot's topics?

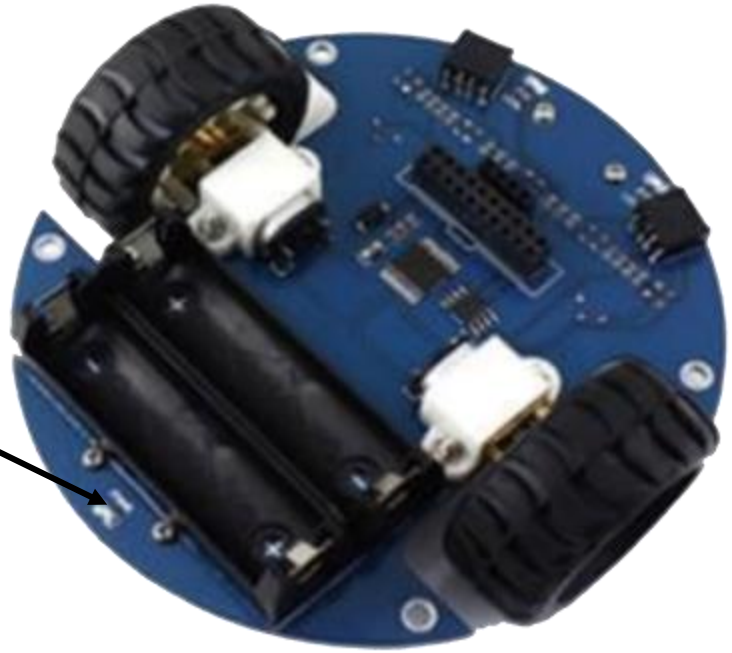
```
rostopic list
```

9. Interesting topics to query: "`/raspicam_node/image/compressed`"

```
rostopic echo "/raspicam_node/image/compressed"
rostopic info "/raspicam_node/image/compressed"
rostopic hz "/raspicam_node/image/compressed"
```

THE ALPHABOT ROBOTS [Charging]

Charge via micro-USB (5V)



ROS CHEAT-SHEET

TÉCNICO LISBOA

Relevant terms to search

Package	Bag
Node	Launch Files
Topic	Parameters
Publisher	TF
Subscriber	RVIZ
Message	Gazebo

Graphical user tools

```
rosrun rviz rviz

rosrun rqt_image_view rqt_image_view

rqt    (can be used to monitor)

rosrun rqt_tf_tree rqt_tf_tree

rosrun rqt_plot rqt_plot
```

Terminal user tools

```
roscore
rosrun <package_name> <node_name>
roslaunch <package_name> <launch_file>
roscd <package_name>

rostopic list
rostopic info <topic_name>
rostopic hz <topic_name>

rosnode list
rosnode info <node_name>

rosbag play <options>
rosbag record <options>

roscreate-pkg <options>

rosservice list
rosservice call <options>

rosmsg list
```

ROS EXTRA NOTES

- Often forgotten – set the environment variables used by ROS

```
source devel/setup.bash
```

- Confirm the definition of the ROS packages path

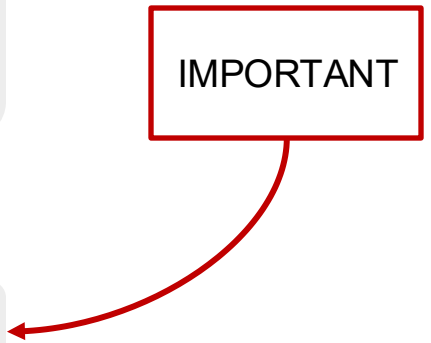
```
echo $ROS_PACKAGE_PATH
```

- ROS/Linux editors: vim or nano [nano is recommended]
- Make use of the .bashrc file

```
source /opt/ros/noetic/setup.bash
source ~/catkin_ws/devel/setup.bash
export EDITOR='nano -w'
```

- Copy a file from the robot to your laptop/Lab computer

```
scp <robot_username>@<robot_ip>:<path_to_file> <location_in_your_computer>
```



ROS EXTRA NOTES [2]

- Explore the use of **`roslaunch`** and launch files
- Bag files may occupy too much space.

  Suggestion: record only the required topics and include compression

```
rosbag record –j <topics>
```

- If problems are detected, run

```
roswtf
```

- To install dependencies of a package, use rosdep

```
sudo apt-get install rosdep
rosdep init
rosdep install <package-name>
```

- ROS log files are located at

```
~/.ros/log
```

ROS EXTRA RESOURCES

- Official ROS website:
  https://www.ros.org/
- ROS Wiki:
  http://wiki.ros.org/
- Core ROS Tutorials:
  http://wiki.ros.org/ROS/Tutorials
  - Beginner Level **[all bullets recommended]**
  - Intermediate Level **[roslaunch tips]**
- TF2 Tutorials:
  http://wiki.ros.org/tf2/Tutorials/
  https://articulatedrobotics.xyz/ready-for-ros-6-tf/
- Robot Model:
  http://wiki.ros.org/robot_model_tutorials
- Visualization:
  http://wiki.ros.org/visualization/Tutorials
- Navigation:
  http://wiki.ros.org/navigation/Tutorials

- Aruco detector:
  https://wiki.ros.org/aruco_detect
- Camera Calibrator:
  http://wiki.ros.org/camera_calibration

- MATLAB [**use ROS to record bags and read them in MATLAB**]
  Open and parse rosbag log file (since R2022a supports ROS Noetic): https://www.mathworks.com/help/ros/ref/rosbag.html

Extra software suggestions

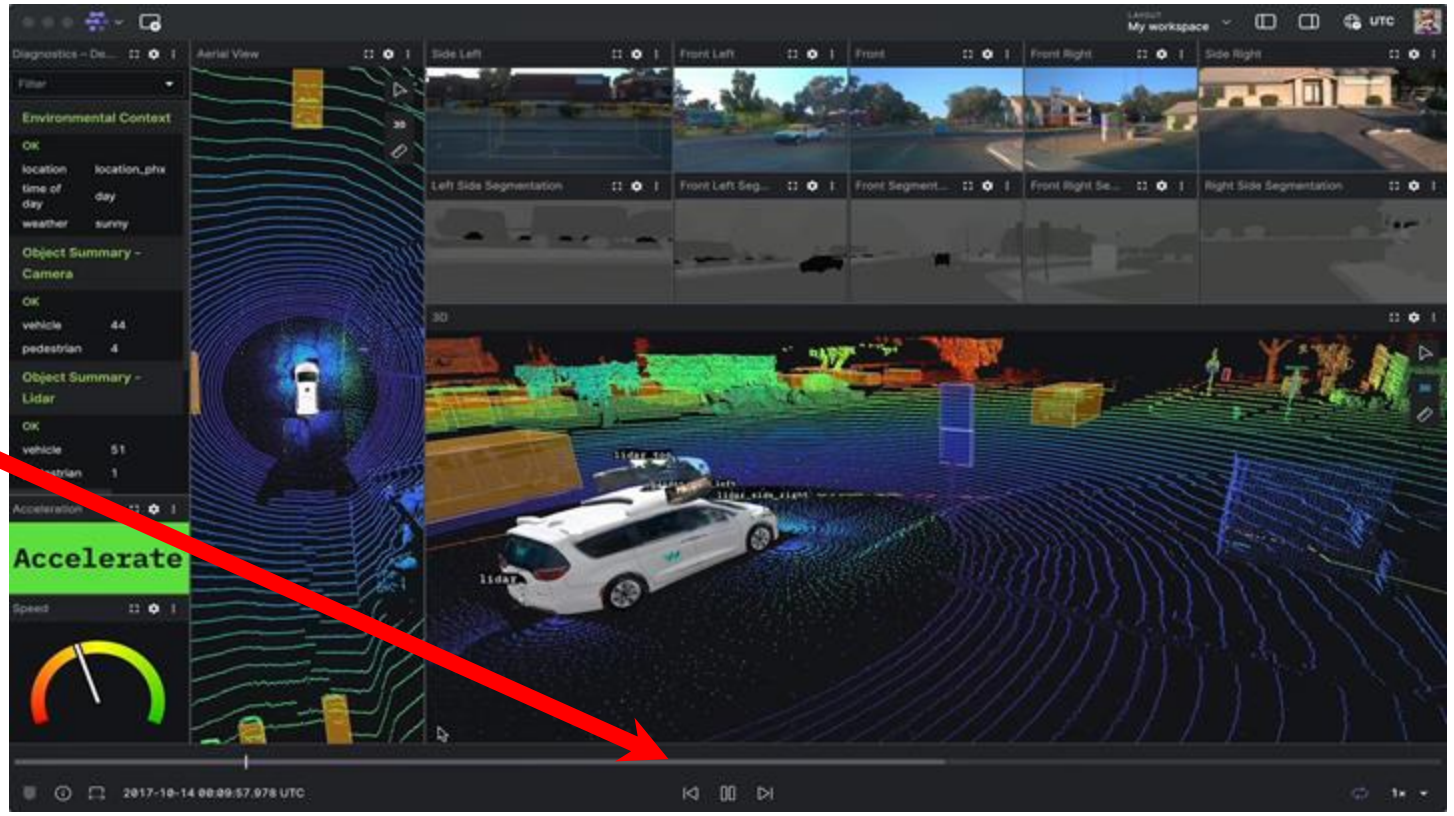
- Recommended to use **Git** in your project's files to **track their changes** over time. Git also allows for **file backup** and **sharing**.
  Attention: share the project only with members of the group and, eventually, with professors of the course. **Do not enable public access**.
- MATLAB can be used to produce graphics from ROS bag files (MATLAB supports supports ROS Noetic since R2022a): open and parse rosbag log file (MATLAB recommended only for plotting purposes) https://www.mathworks.com/help/ros/ref/rosbag.html)

```
bag = rosbag(filename)
bagInfo = rosbag('info',filename)
rosbag info filename
```

Extra software suggestions (cont.)

- **Foxglove** is a Rviz alternative, with data management and timeline visualization capabilities.

  Available for Linux, Windows and macOS.
  https://foxglove.dev/



Getting Hands-On: ROS in Action with a Robot

TÉCNICO LISBOA

- Select a **physical robot** for a first trial
- Connect to the robot and **list topics**
- **Visualize in real time sensor data** (e.g. Rviz, or Foxglove)
- **Move the robot** using the keyboard, while visualizing sensor data
- **Record a bag**, transfer it to an external computer, and visualize the data with **rosbag play**