MODULE 6:
DEVELOPING BASIC AUTONOMOUS VEHICLE SYSTEMS

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Agenda for Day 4

1. Very Short Lecture (Chapter 1 & 2)
2. RECAP on yesterday's practice
3. Day 4 workshops [Physical TB3 (base only)] followed by Project 4
4. Cont M5 [simulation workshop] on virtual mobile-manipulator (TB3 with OM)
5. Day 4 workshops [Virtual TB3 with OM] followed by Project 5

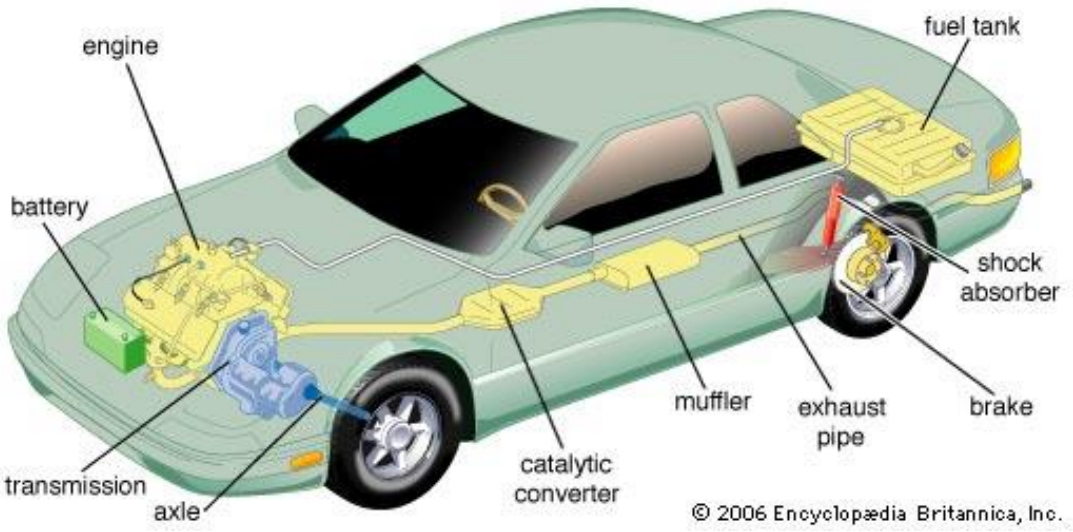
Contents

1. Automotive Basics
2. Step-by-Step guidelines on how to develop basic autonomous vehicle systems
3. Workshop: Develop basic autonomous vehicle systems

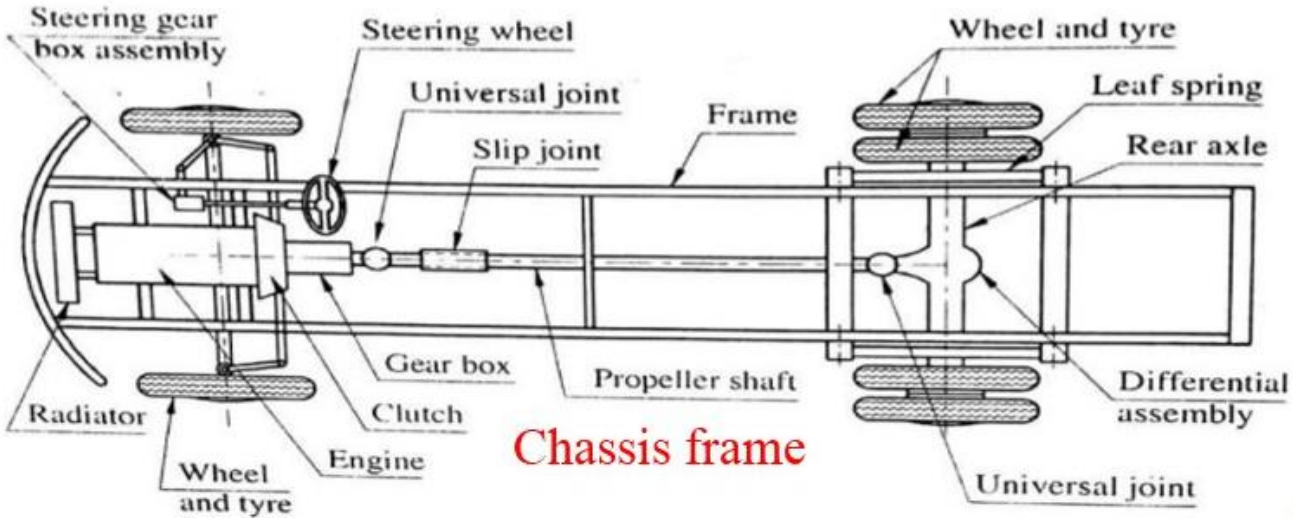
CHAPTER 1:
AUTOMOTIVE BASICS

Main Parts of Automobile

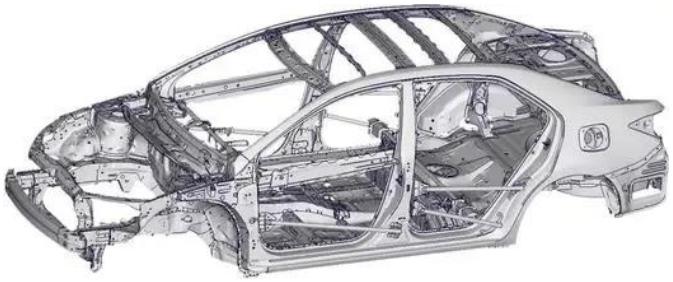
1. The Chassis
2. The Engine
3. The Transmission System
4. The Body



The Chassis

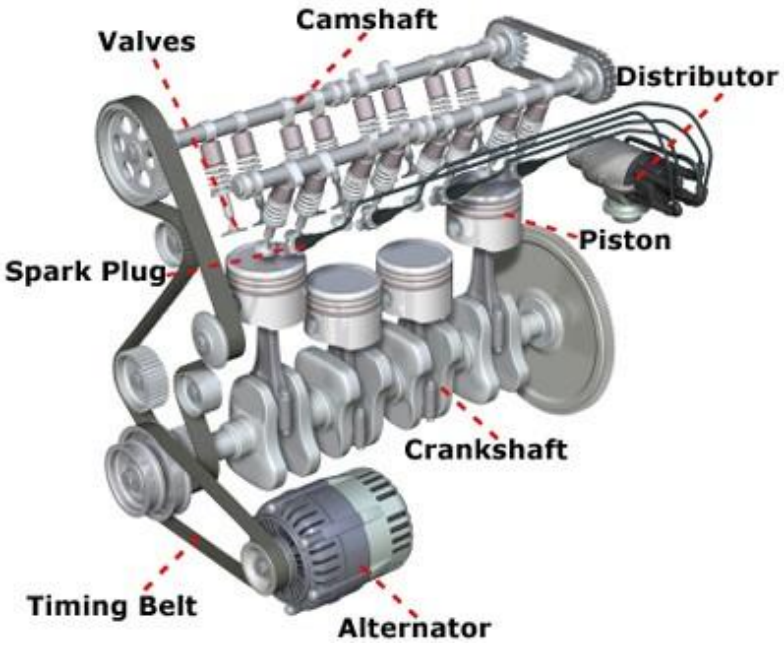


- **Main skeleton of vehicle**
- Supports engine, power transmission, and car body



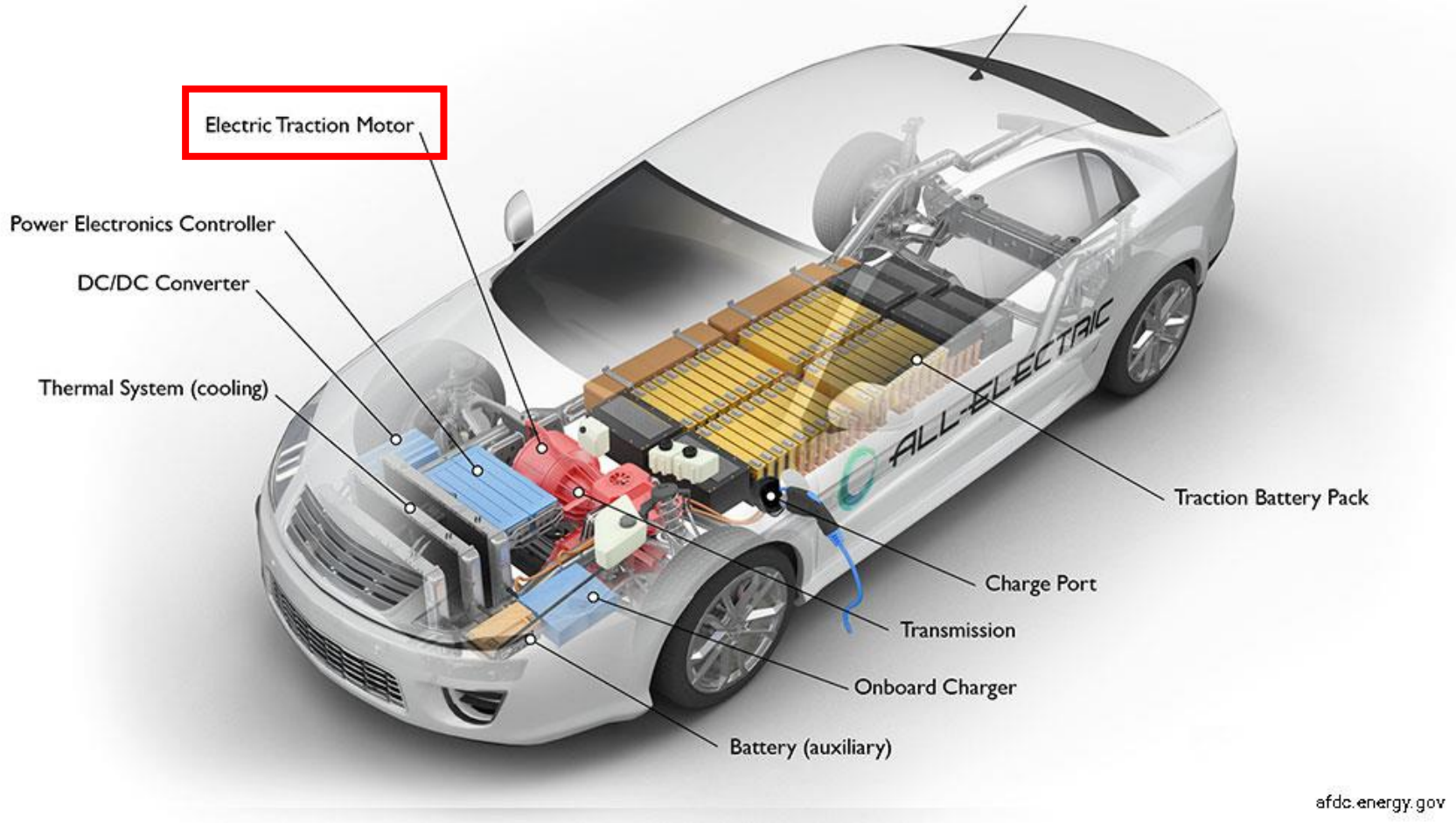
The Engine

- **Source of mechanical power to an automobile**
- E.g. internal combustion engine for general vehicles, electric motor for all-electric vehicles (EVs)



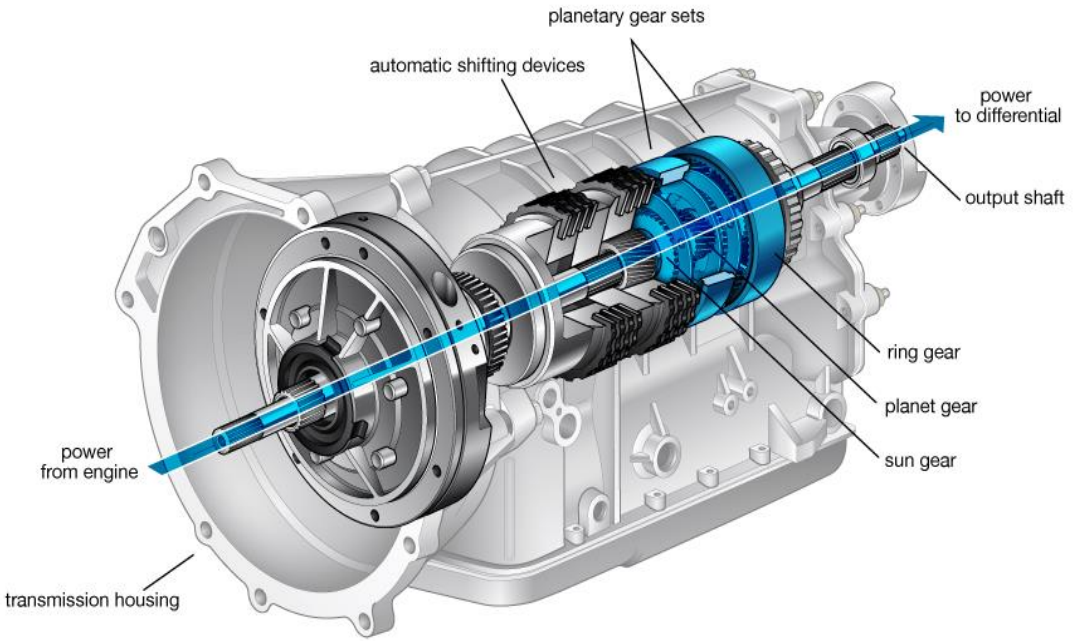
The Engine

All-Electric Vehicle



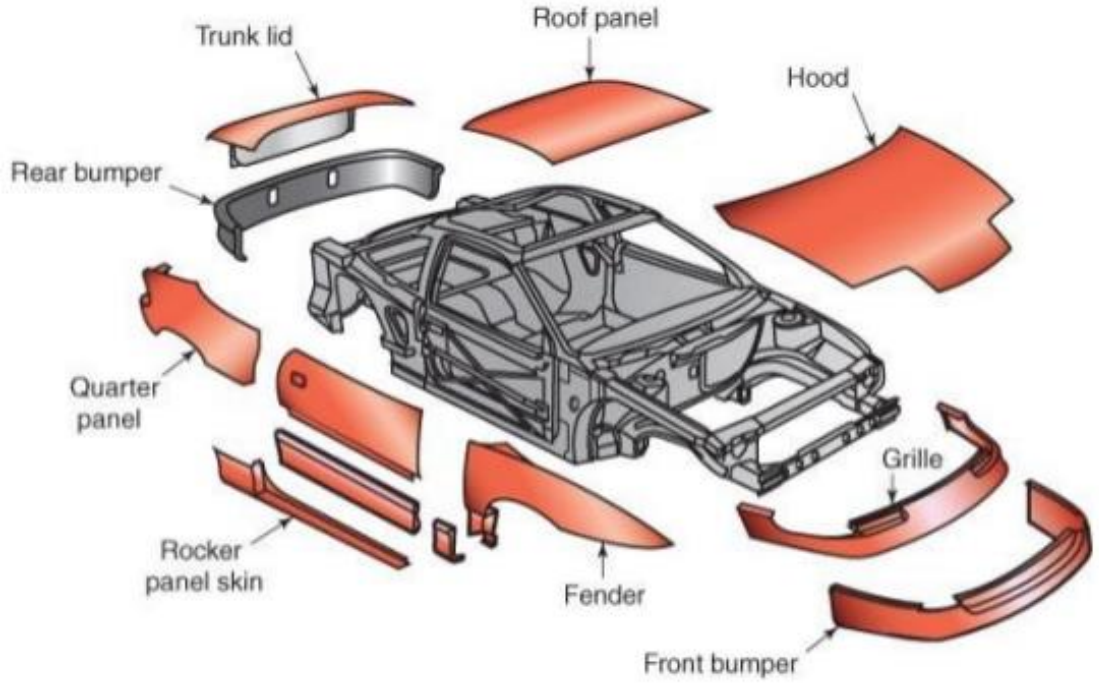
The Transmission System

- **Transmits power from the engine to the wheels**
- Rotation movement transferred to the wheels → leads to their rotary motion → leads to vehicle movement

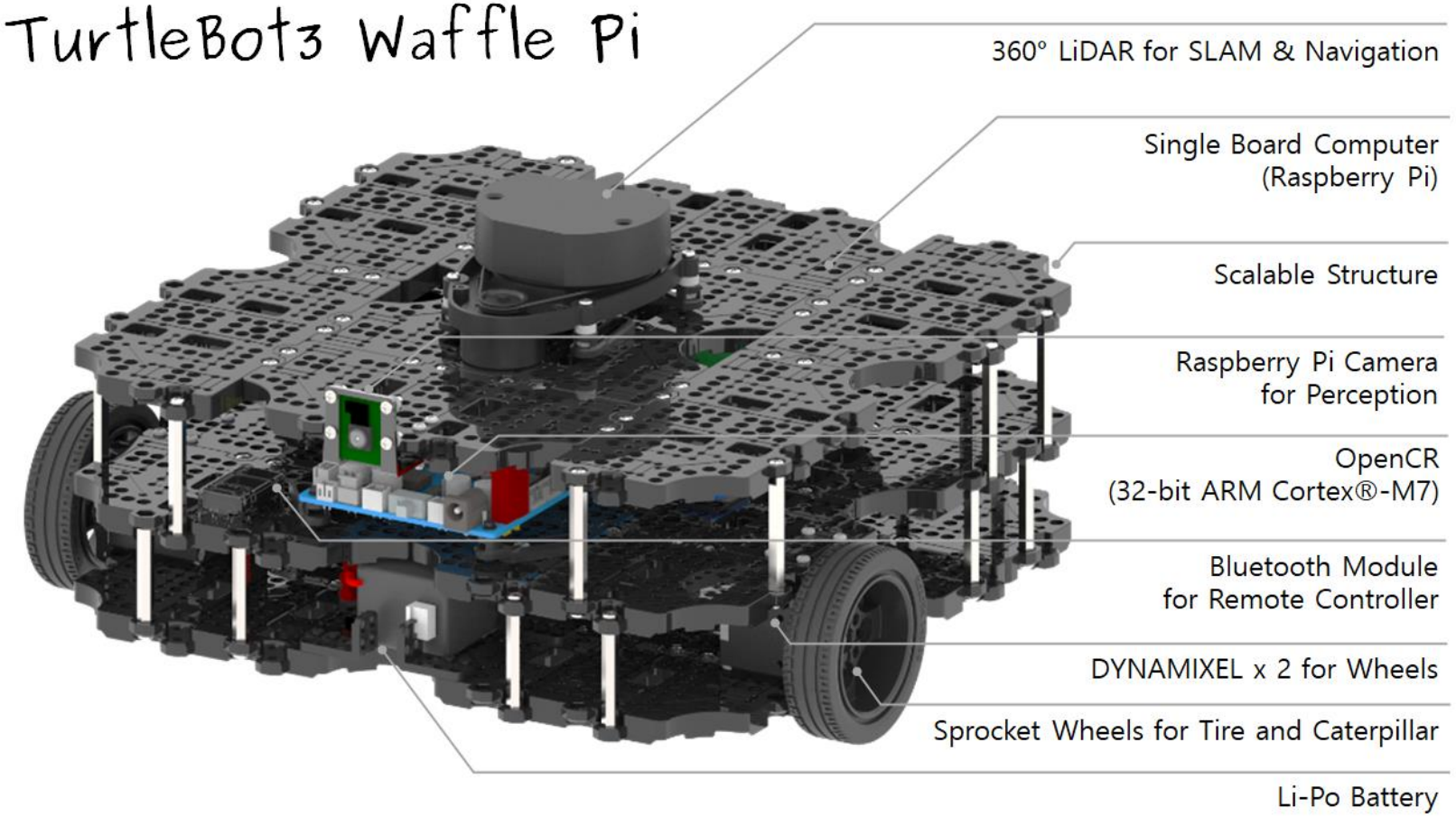


The Body

- To **protect the crucial car components** (i.e. engine, transmission system, braking/steering system) **and the passengers** from damages and/or bad weather
- Attached onto the Chassis



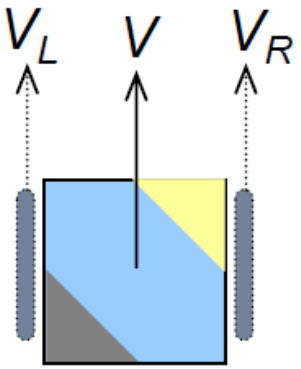
Main Parts of Automobile



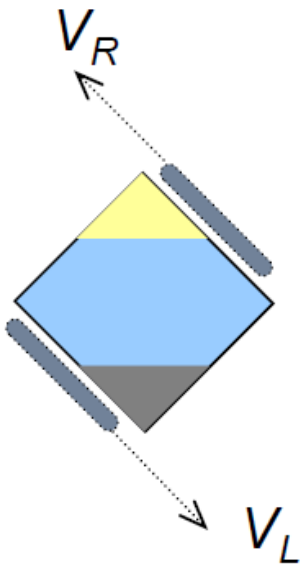
Where are the 4 main components for the TB3?

Differential Drive

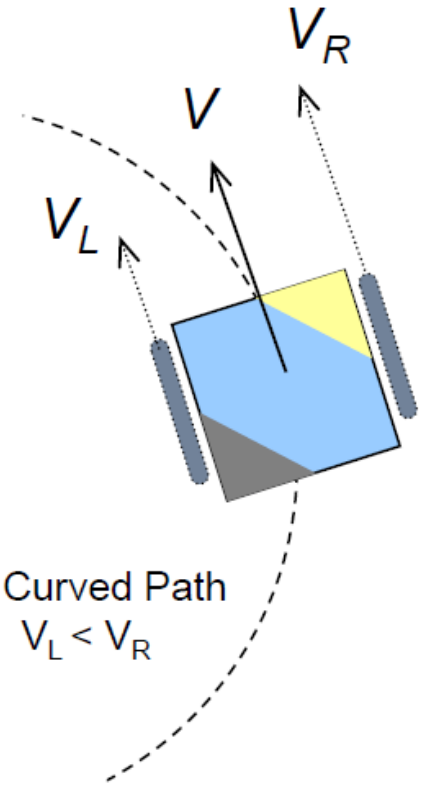
Consider the two-wheeled differential drive robot (e.g. the TB3):



(a) Straight line motion
$V = V_L = V_R$



(b) Rotation about stationary position
$V_L = -V_R$



(c) Curved Path
$V_L < V_R$

Differential Drive

Advantages:

- **Ease of implementation**
- **Simpler to control**
- **Ability to change orientation** on the same spot

Disadvantages:

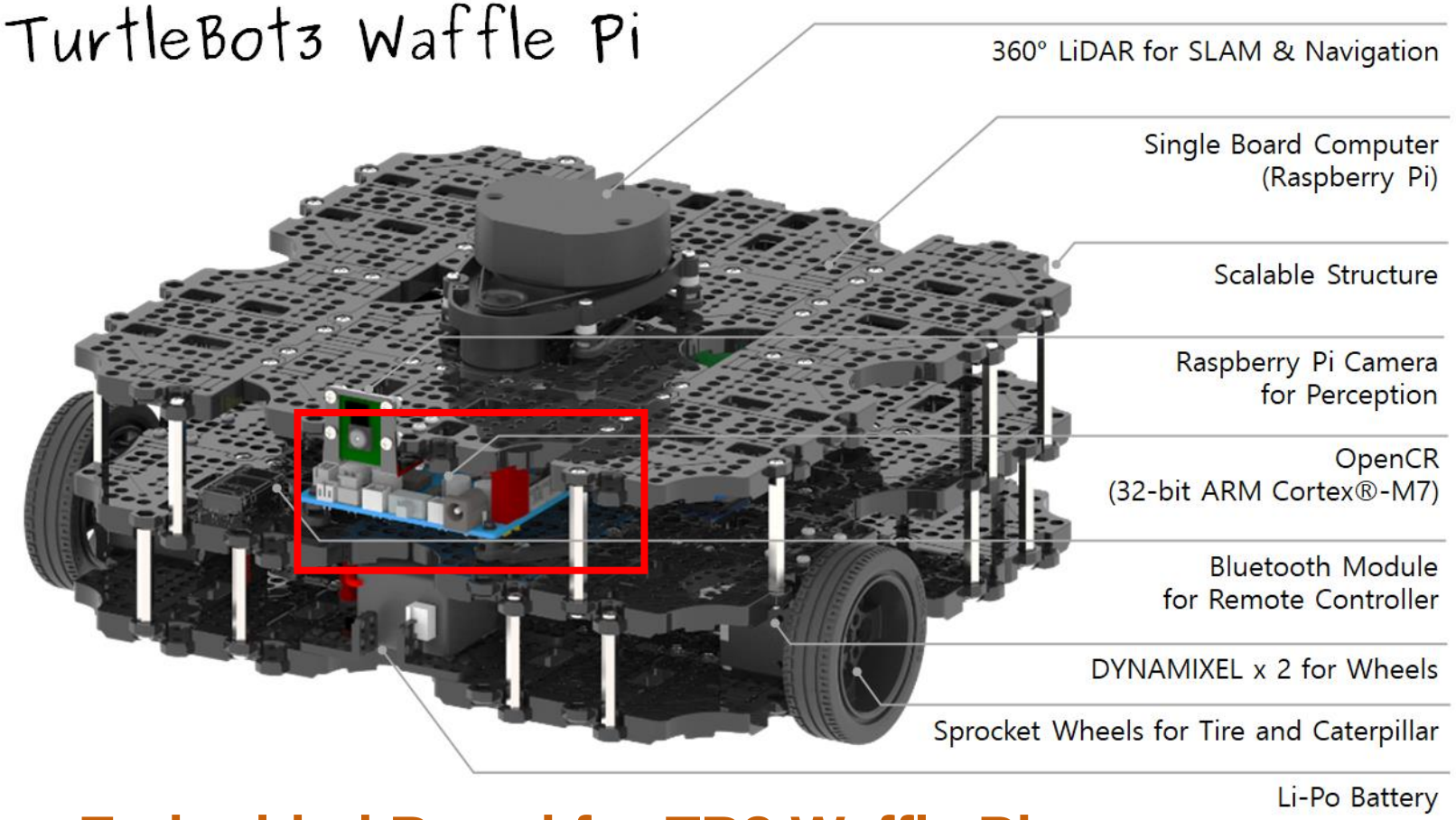
- **Not as efficient** as Ackerman steering or independently steered wheels when 4 or more wheels are used
  - Some of the wheels need to skid to some extent in order to complete the turn
- **Unstable at high speeds**

CHAPTER 2:
STEP-BY-STEP GUIDELINES ON HOW TO DEVELOP BASIC AUTONOMOUS VEHICLE SYSTEMS

What is Needed?

1. **Basic automotive parts** (e.g. chassis, engine/motor, transmission system, fuel/battery)
2. **Software** (e.g. ROS)
3. **Embedded board**; the Controller (e.g. OpenCR)
4. **Personal Computer** (e.g. Raspberry Pi)
5. **Sensory Systems** (e.g. LIDAR, camera)

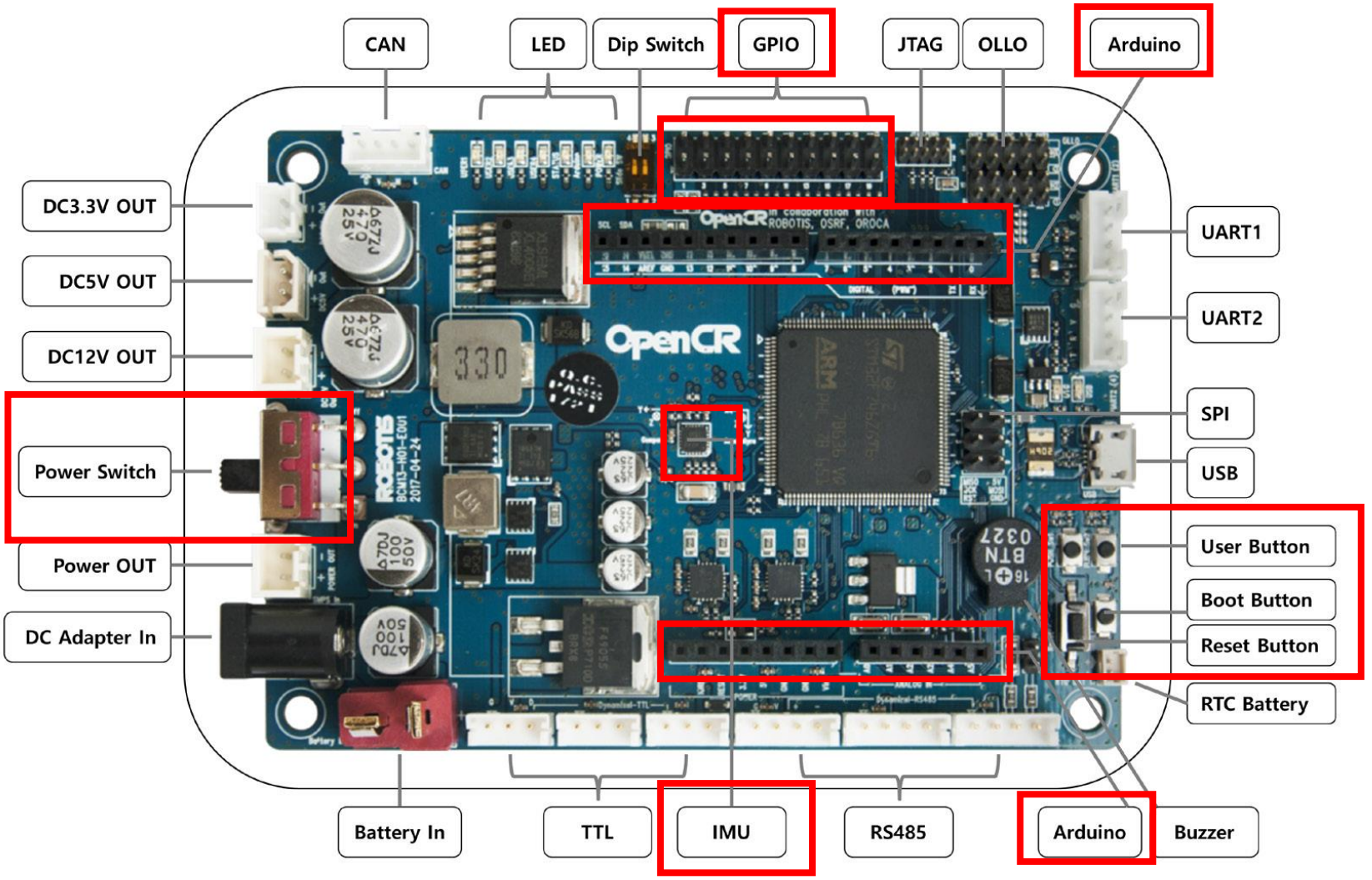
What is Needed?



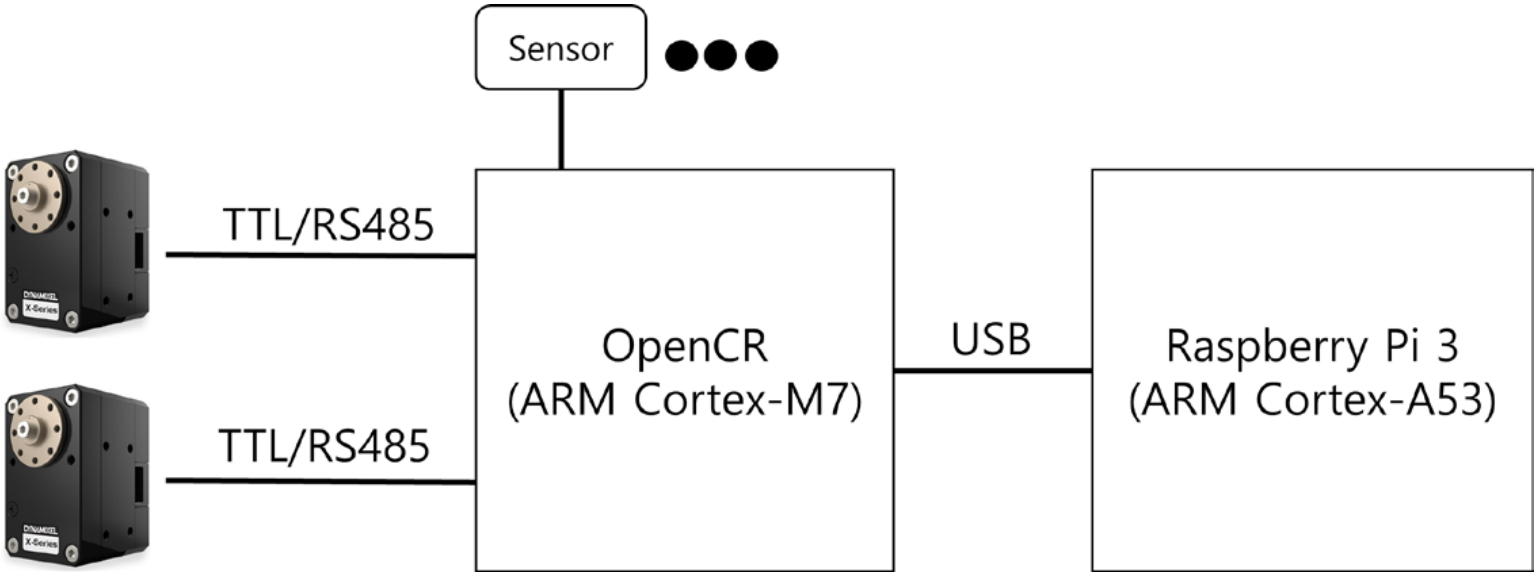
Embedded Board for TB3 Waffle Pi:

- **OpenCR**

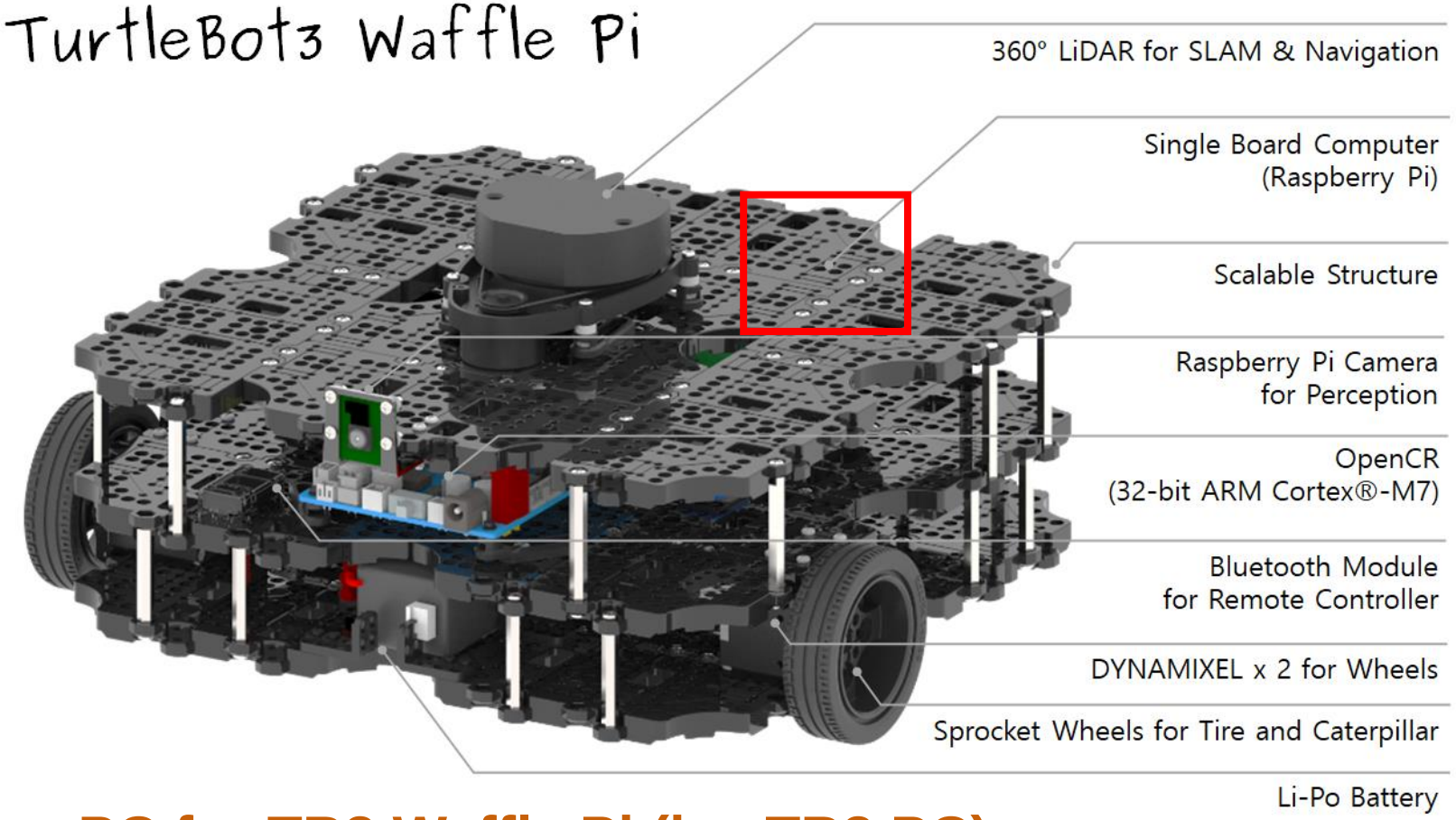
OpenCR Interface Configuration (RECAP)



TB3 Embedded System Configuration



What is Needed?



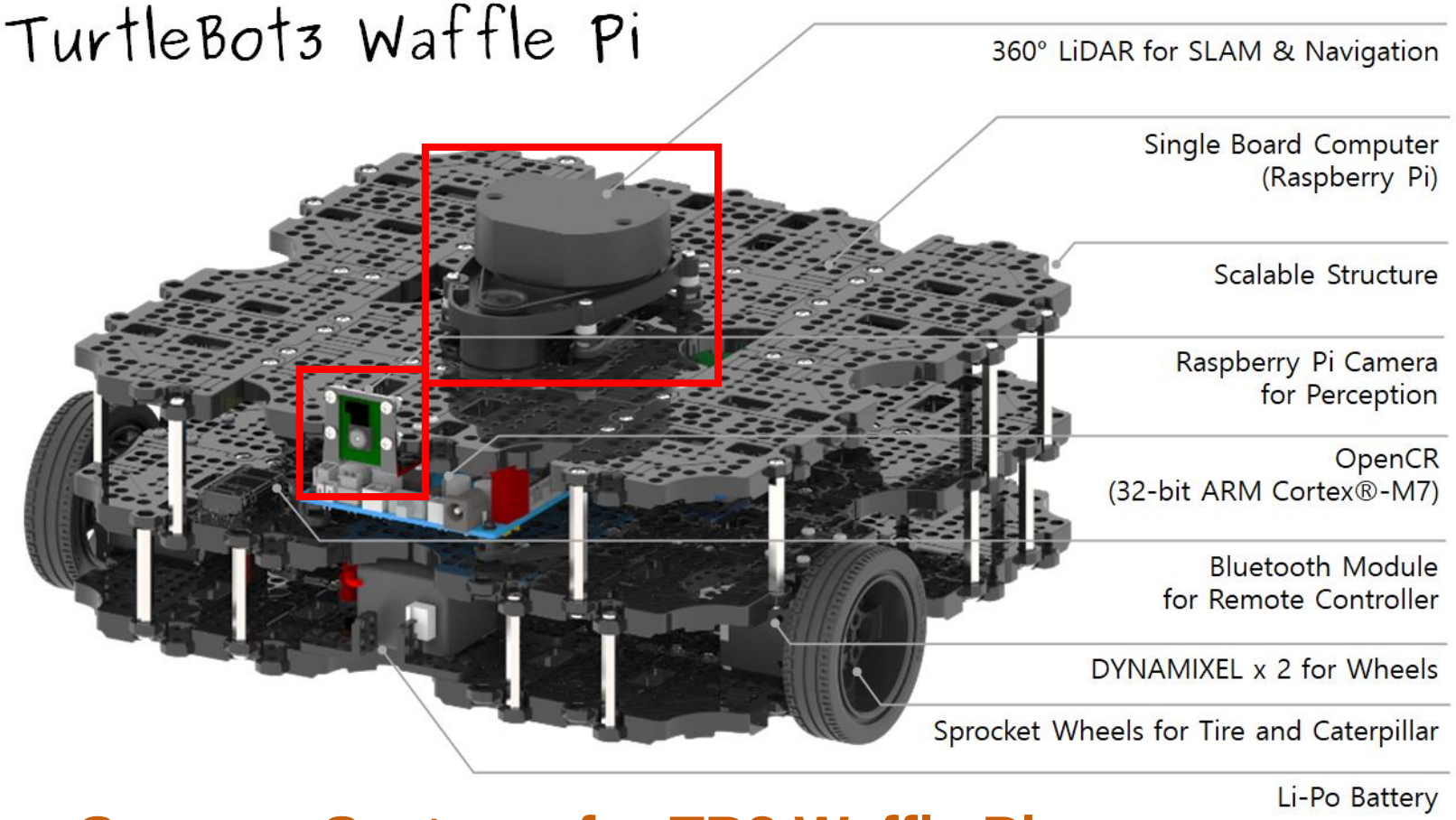
PC for TB3 Waffle Pi (i.e. TB3 PC):

- **Raspberry Pi**

TB3 PC – Raspberry Pi

- **Main computer of the TB3**
- Enough to use the basic features of TB3 (e.g. **ROS**)
- Enable user to **communicate** with the TB3 from remote PC; connectivity between TB3 PC and remote PC

What is Needed?



Sensory Systems for TB3 Waffle Pi:

- **Camera, LIDAR**

WORKSHOP: DEVELOP BASIC AUTONOMOUS VEHICLE SYSTEMS

DEMO of TB3

NICF- Autonomous Robots and Vehicles (SF)

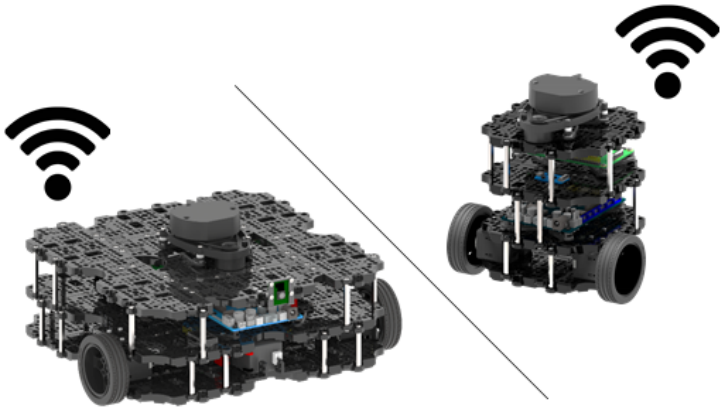
Important to know b4 we cont!

Remote PC:

TB3 PC:

Configure Network

TurtleBot



Remote PC

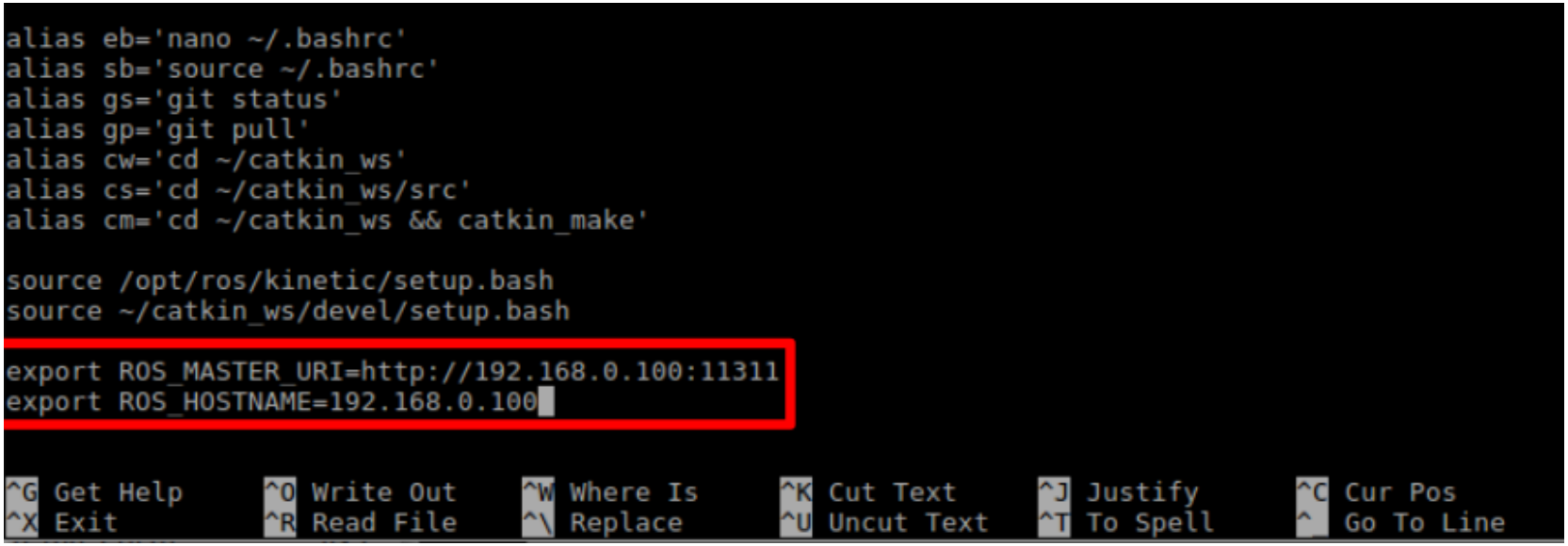
ROS_MASTER_URI = http://IP_OF_REMOTE_PC:11311
ROS_HOSTNAME = IP_OF_TURTLEBOT

ROS_MASTER_URI = http://IP_OF_REMOTE_PC:11311
ROS_HOSTNAME = IP_OF_REMOTE_PC

```
$ ifconfig
```

Configure Network

```
$ nano ~/.bashrc
```



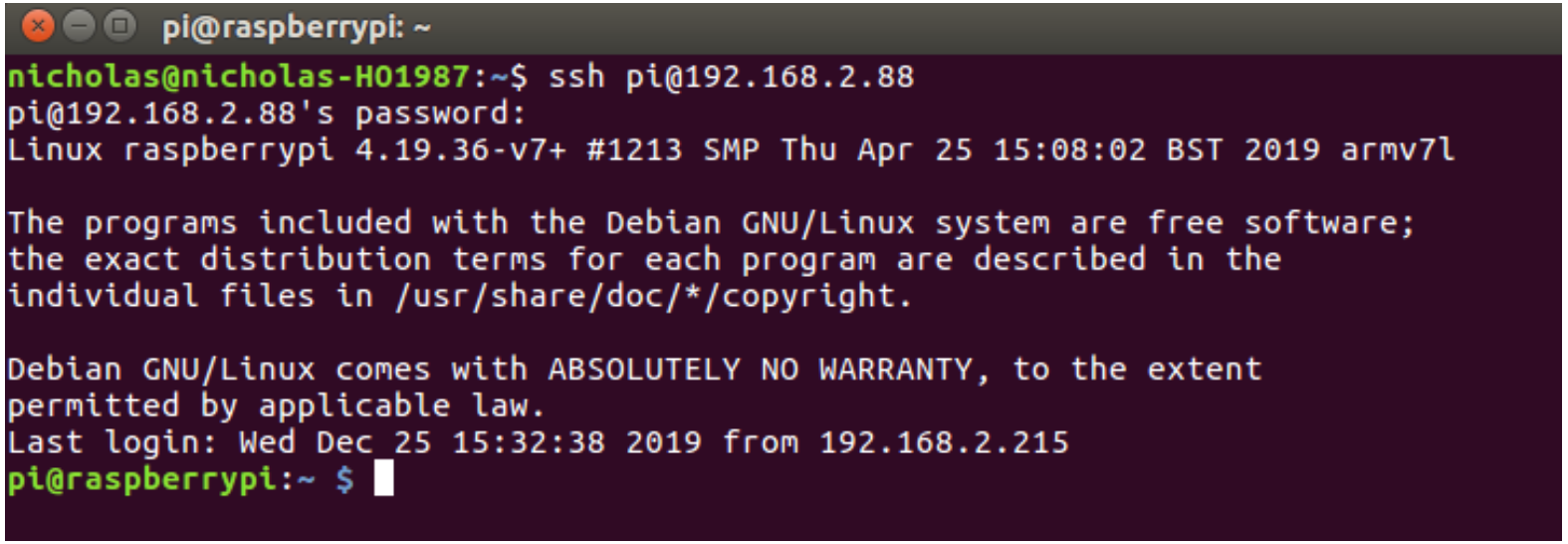

```
$ source ~/.bashrc
```

CONTROL TB3 WITH ROS

OpenCR Setup

This setup only requires you to **do it ONCE!**

1. **On the Remote PC**, open new terminal and type the following commands to access TB3 PC:
   - `$ ssh ubuntu@192.168.XX.XX`
   - You will see that the Remote PC will log into the Raspberry Pi which is the TB3 PC



OpenCR Setup

This setup only requires you to **do it ONCE!**

2. **On the TB3 PC**, type the following codes in order to upload the firmware to the OpenCR
   - `$ export OPENCR_PORT=/dev/ttyACM0`
   - `$ export OPENCR_MODEL=waffle`
   - `$ rm -rf ./opencr_update.tar.bz2`
   - `$ wget https://github.com/ROBOTIS-GIT/OpenCR-Binaries/raw/master/turtlebot3/ROS1/latest/opencr_update.tar.bz2 && tar -xvf opencr_update.tar.bz2 && cd ./opencr_update && ./update.sh $OPENCR_PORT $OPENCR_MODEL.opencr && cd ..`

OpenCR Setup

This setup only requires you to **do it ONCE!**

The following will appear on the terminal:

```
opencr_update/burger_turtlebot3_core.ino.bin
opencr_update/waffle_turtlebot3_core.ino.bin
opencr_update/opencr_ld_shell_arm
opencr_update/update.sh
opencr_update/
opencr_update/opencr_ld_shell_x86
opencr_update/waffle.opencr
opencr_update/burger.opencr
opencr_update/released_1.0.17.txt
armv7l
arm
OpenCR Update Start..
opencr_ld_shell ver 1.0.0
opencr_ld_main
[   ] file name          : waffle.opencr
[   ] file size          : 172 KB
[   ] fw_name            : waffle
[   ] fw_ver             : 1.0.17
[OK] Open port           : /dev/ttyACM0
[   ]
[   ] Board Name         : OpenCR R1.0
[   ] Board Ver          : 0x17020800
[   ] Board Rev          : 0x00000000
[OK] flash_erase         : 0.93s
[OK] flash_write         : 1.23s
[OK] CRC Check           : 119909C 119909C , 0.006000 sec
[OK] Download
[OK] jump_to_fw
```

When firmware upload is completed successfully, `jump_to_fw` text string will be printed on the terminal

Bringup

- The **Bringup steps below must be executed first to activate TB3 before you can execute commands** to control the TB3
- Bringup the TB3 (without Manipulator)
  1. **On the Remote PC**, run roscore (**Important: do NOT run roscore under the TB3 PC!!!**)

     ```
     $ roscore
     ```

  2. **On the Remote PC**, open new terminal and type the following commands to access TB3 PC:

     ```
     $ ssh ubuntu@192.168.XX.XX
     ```

     You will see in this terminal that you are connected to the pi's terminal
  3. **On the TB3 PC** (using the linked pi terminal), type the following to bring up basic packages to start TB3:

     ```
     $ roslaunch turtlebot3_bringup
     turtlebot3_robot.launch
     ```

Bringup

Other Bringup commands if you want to **launch Raspberry Pi Camera separately**:

```
$ roslaunch turtlebot3_bringup
turtlebot3_rpicamera.launch
```

Note that: `$ roslaunch turtlebot3_bringup turtlebot3_robot.launch` will activate the LIDAR and the core together but not the Raspberry Pi Camera, hence need to activate the camera separately

Basic Operation

1. Topic Monitor

- Helps you **monitor topics (i.e. status) of the TB3**
- E.g. battery state, velocity/position, joint states, odom, sensor states, transmission status
- **Utilizes rqt provided by ROS**; a Qt-based framework for GUI development for ROS

Basic Operation

1. Topic Monitor

- Switch on TB3 and activate Bringup first
- Ensure TB3 has enough space to move around
- **On the Remote PC, run rqt**

```
$ rqt
```

- **On the Remote PC, run rqt_image_view for camera view only**

```
$ rqt_image_view
```

Basic Operation

1. Topic Monitor (cont); rqt example:

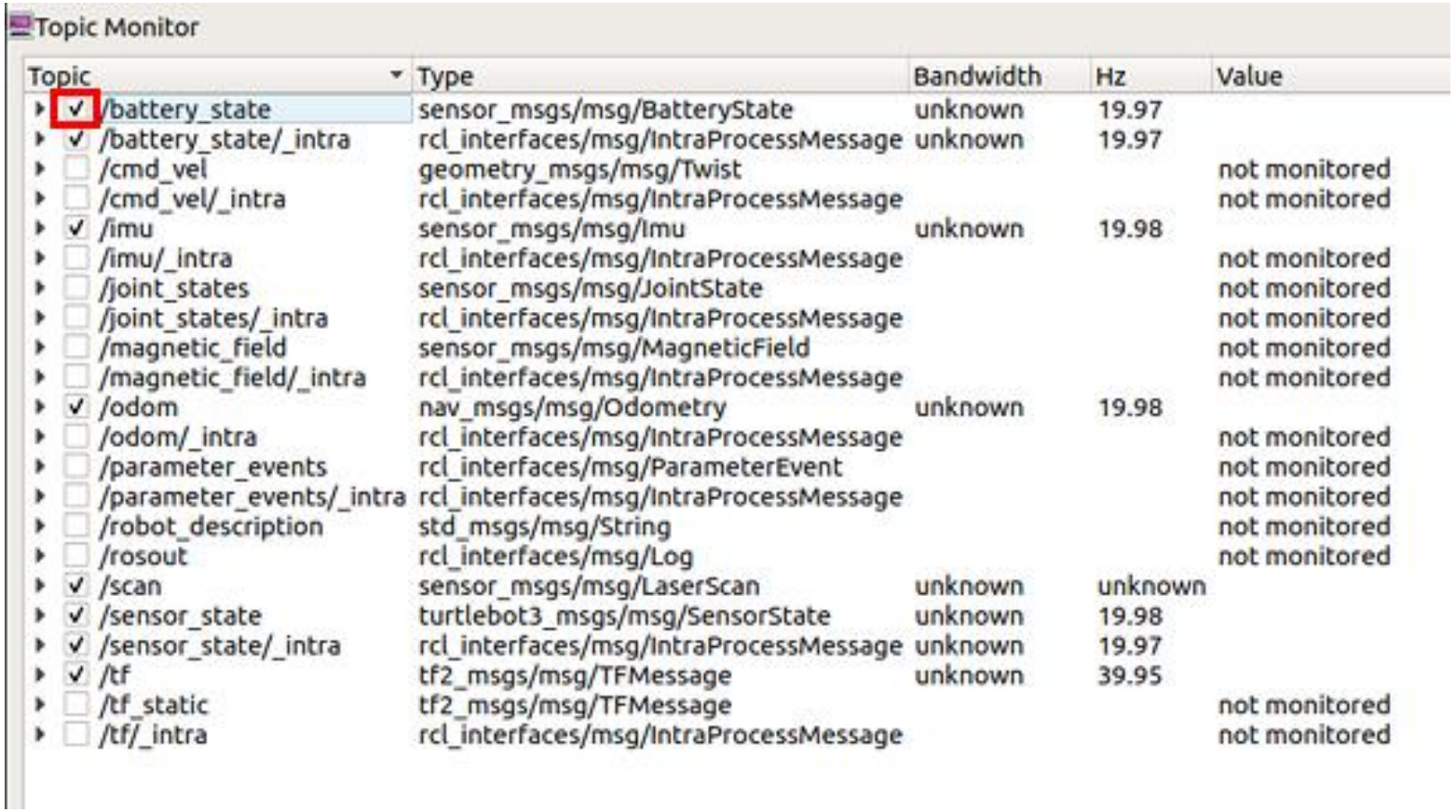
Topic Monitor

Topic	Type	Bandwidth	Hz	Value
/battery_state	sensor_msgs/msg/BatteryState			not monitored
/battery_state/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/cmd_vel	geometry_msgs/msg/Twist			not monitored
/cmd_vel/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/imu	sensor_msgs/msg/Imu			not monitored
/imu/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/joint_states	sensor_msgs/msg/JointState			not monitored
/joint_states/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/magnetic_field	sensor_msgs/msg/MagneticField			not monitored
/magnetic_field/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/odom	nav_msgs/msg/Odometry			not monitored
/odom/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/parameter_events	rcl_interfaces/msg/ParameterEvent			not monitored
/parameter_events/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/robot_description	std_msgs/msg/String			not monitored
/rosout	rcl_interfaces/msg/Log			not monitored
/scan	sensor_msgs/msg/LaserScan			not monitored
/sensor_state	turtlebot3_msgs/msg/SensorState			not monitored
/sensor_state/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
/tf	tf2_msgs/msg/TFMessage			not monitored
/tf_static	tf2_msgs/msg/TFMessage			not monitored
/tf/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored

Basic Operation

1. Topic Monitor

- **Click on the checkbox to monitor the topic**

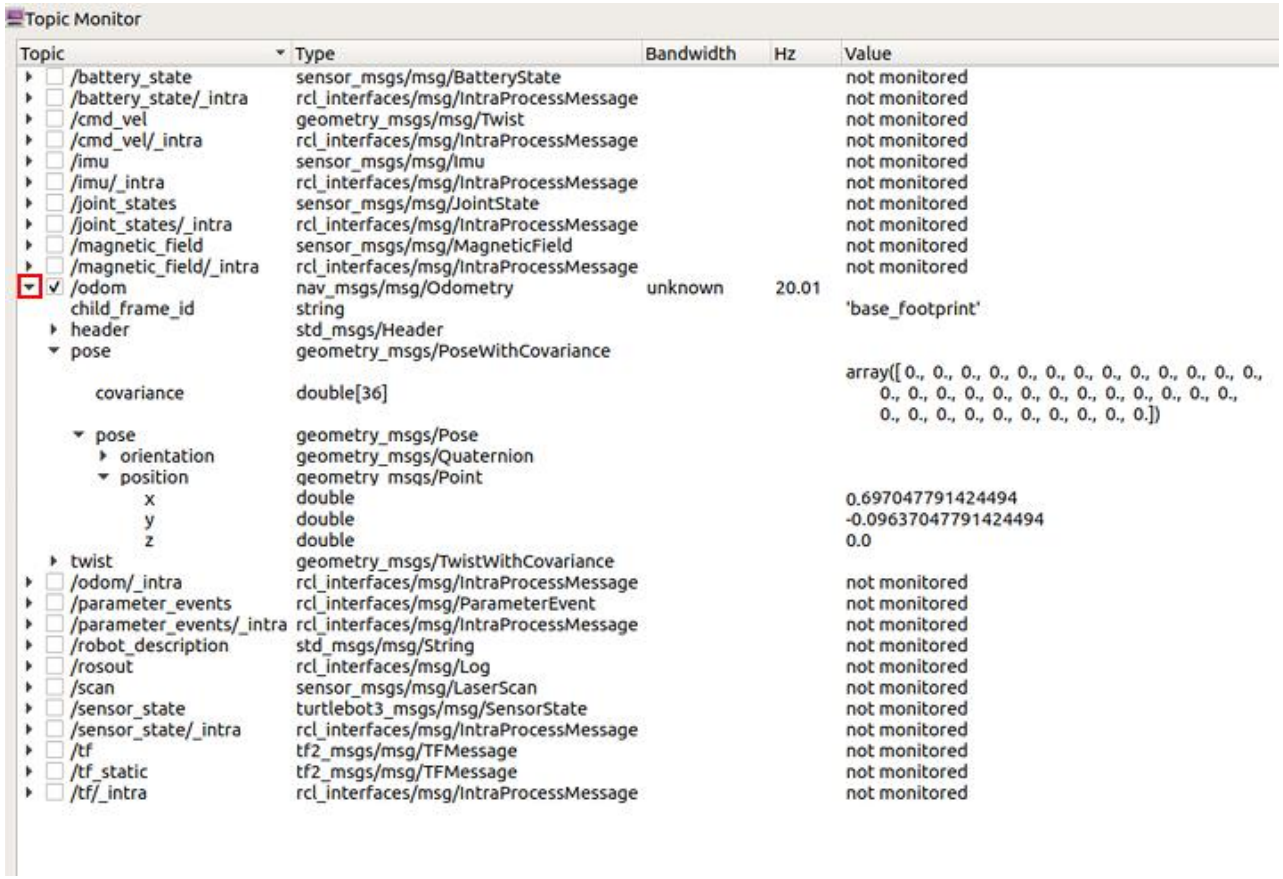


Topic	Type	Bandwidth	Hz	Value
☑ /battery_state	sensor_msgs/msg/BatteryState	unknown	19.97	
☑ /battery_state/_intra	rcl_interfaces/msg/IntraProcessMessage	unknown	19.97	
☐ /cmd_vel	geometry_msgs/msg/Twist			not monitored
☐ /cmd_vel/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☑ /imu	sensor_msgs/msg/Imu	unknown	19.98	
☐ /imu/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☐ /joint_states	sensor_msgs/msg/JointState			not monitored
☐ /joint_states/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☐ /magnetic_field	sensor_msgs/msg/MagneticField			not monitored
☐ /magnetic_field/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☑ /odom	nav_msgs/msg/Odometry	unknown	19.98	
☐ /odom/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☐ /parameter_events	rcl_interfaces/msg/ParameterEvent			not monitored
☐ /parameter_events/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored
☐ /robot_description	std_msgs/msg/String			not monitored
☐ /rosout	rcl_interfaces/msg/Log			not monitored
☑ /scan	sensor_msgs/msg/LaserScan	unknown	unknown	
☑ /sensor_state	turtlebot3_msgs/msg/SensorState	unknown	19.98	
☑ /sensor_state/_intra	rcl_interfaces/msg/IntraProcessMessage	unknown	19.97	
☑ /tf	tf2_msgs/msg/TFMessage	unknown	39.95	
☐ /tf_static	tf2_msgs/msg/TFMessage			not monitored
☐ /tf/_intra	rcl_interfaces/msg/IntraProcessMessage			not monitored

Basic Operation

1. Topic Monitor

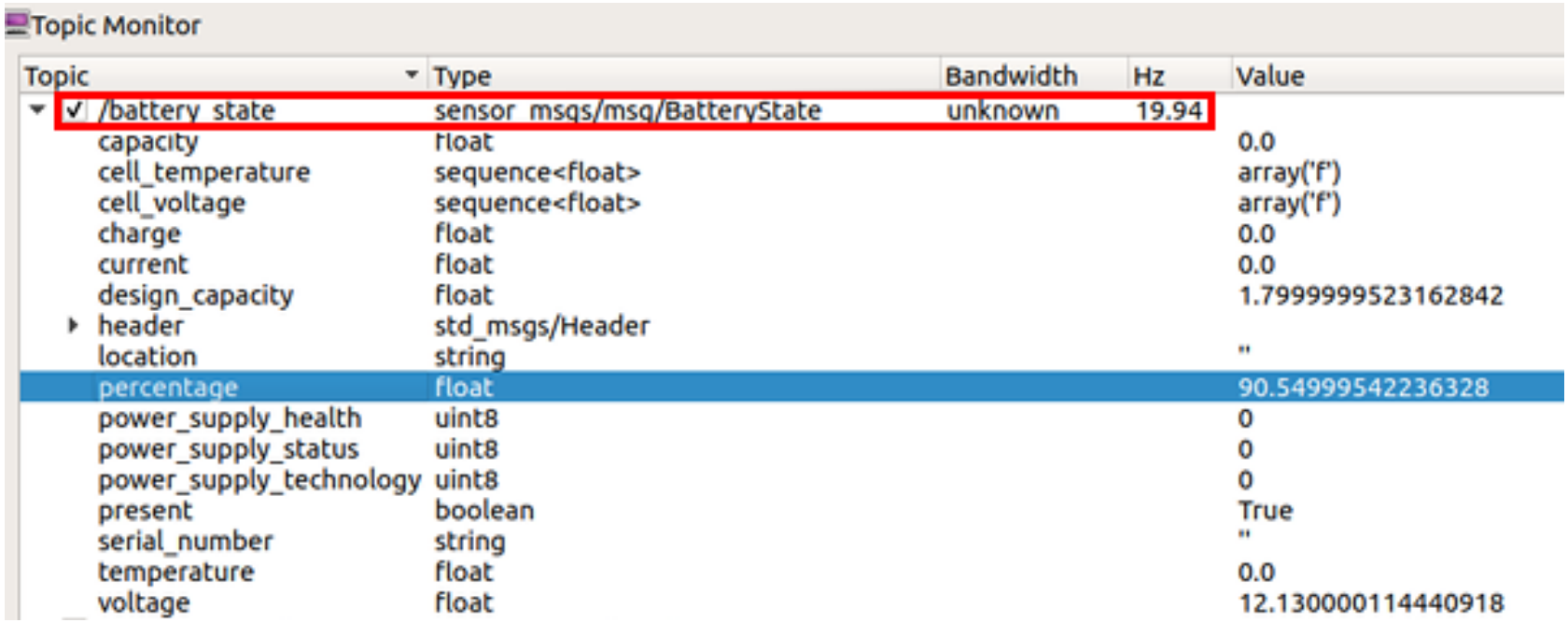
- **Expand the topic by clicking on the ▶ button next to the checkbox for more details**



Basic Operation

1. Topic Monitor

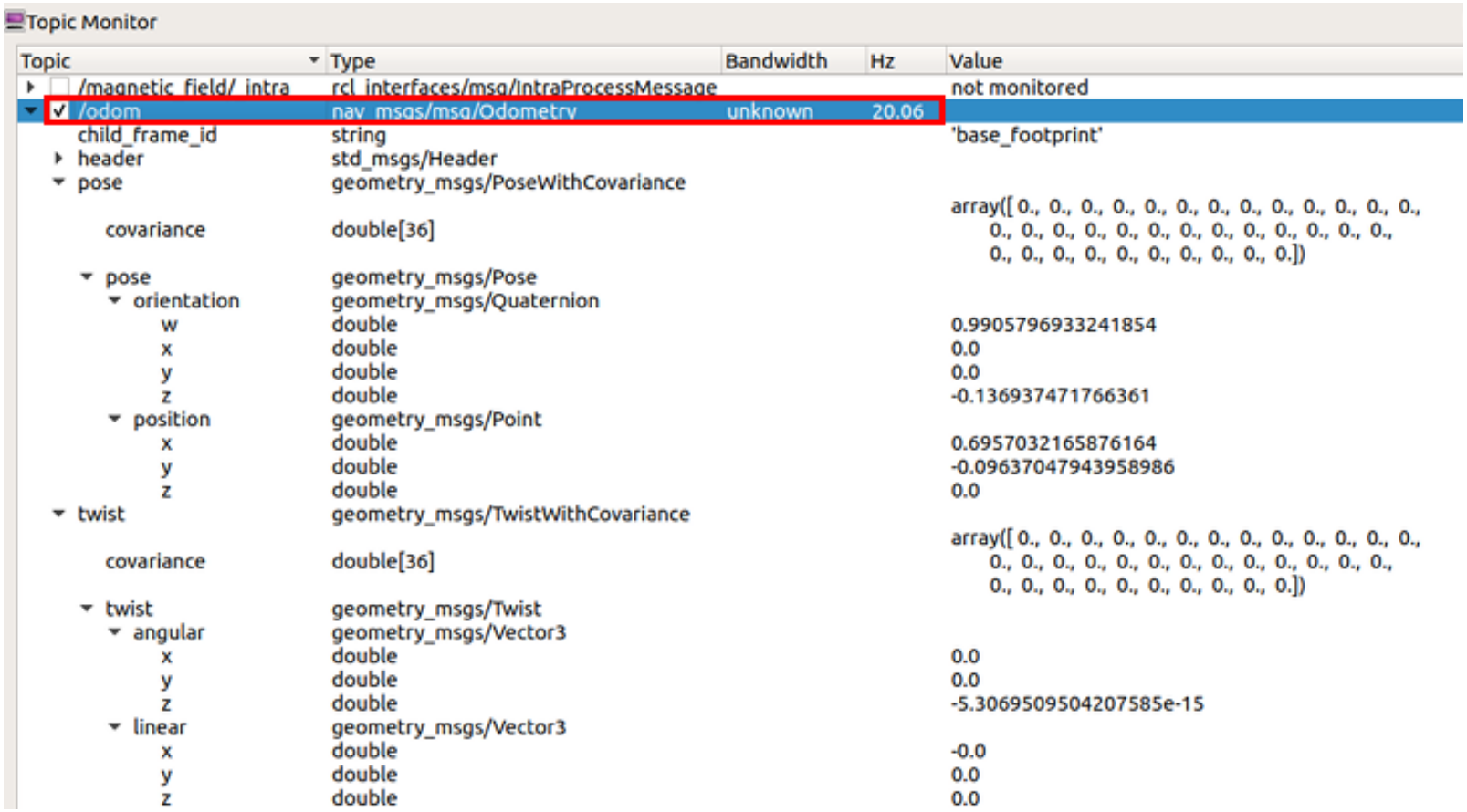
`/battery_state` → related to battery condition



Basic Operation

1. Topic Monitor

`/odom` → related to odometry of the TB3



Basic Operation

2. Teleoperation (aka manual operations)

Using Keyboard:

- Switch on TB3 and activate Bringup first
- Ensure TB3 has enough space to move around
- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_teleop
turtlebot3_teleop_key.launch
```

- Control the TB3 using the keys w, a, s, d, x
  - w/x : increase/decrease linear velocity
  - a/d : increase/decrease angular velocity
  - space key, s : force stop
  - CTRL-C to quit

Basic Operation

2. Teleoperation (aka manual operations)

Using ROBOTIS RC100 controller (Bluetooth):

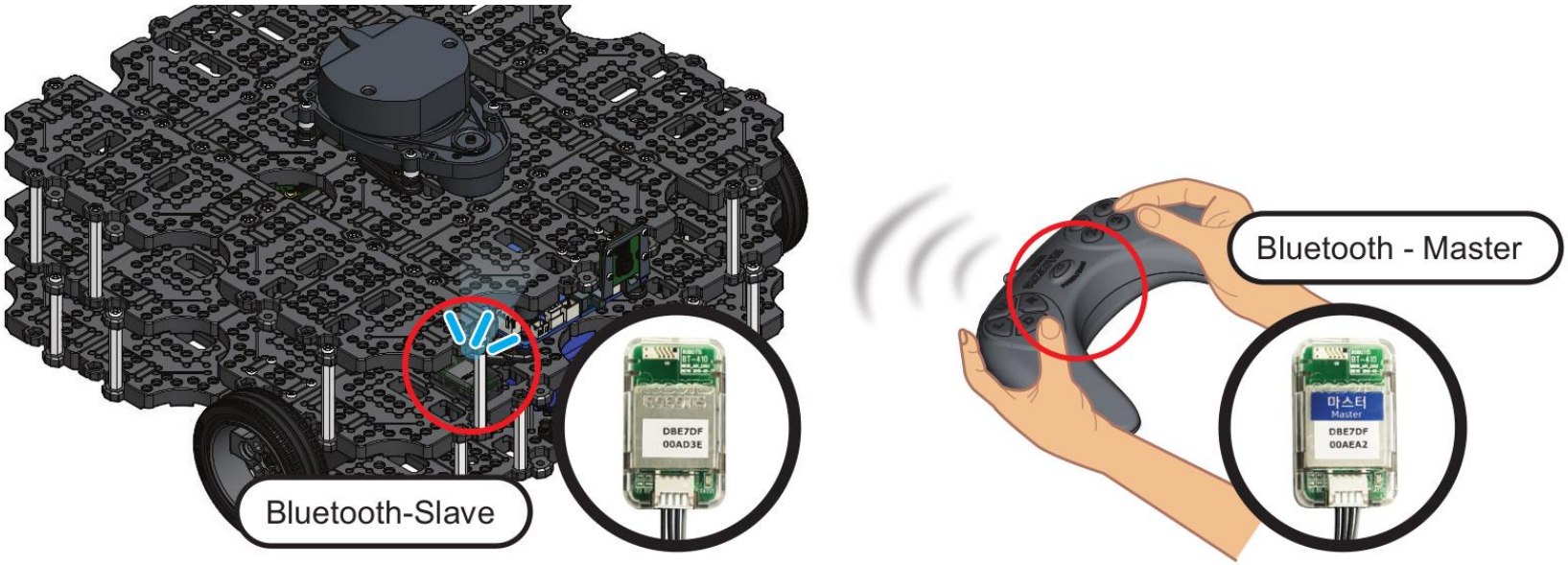
- Switch on TB3
- Ensure TB3 has enough space to move around
- Switch on the controller with the Bluetooth (master) module; the TB3 has the slave module
- Hit the buttons on the controller to move the TB3.

Note: When using RC-100, it is not necessary to execute a specific node because turtlebot_core node creates a /cmd_vel topic in the firmware directly connected to OpenCR

Basic Operation

2. Teleoperation (aka manual operations)

Using ROBOTIS RC100 controller (Bluetooth):



Note: When using RC-100, it is not necessary to execute a specific node because turtlebot_core node creates a /cmd_vel topic in the firmware directly connected to OpenCR

3. Basic examples

Move using Interactive Markers on RViz (using the Markers to rotate or translate the TB3). **Steps:**

- Switch on TB3 and activate basic Bringup first
- Ensure TB3 has enough space to move around
- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_bringup
turtlebot3_remote.launch
```

Skip this if have errors; not important

- **On the Remote PC**, open new terminal and type:

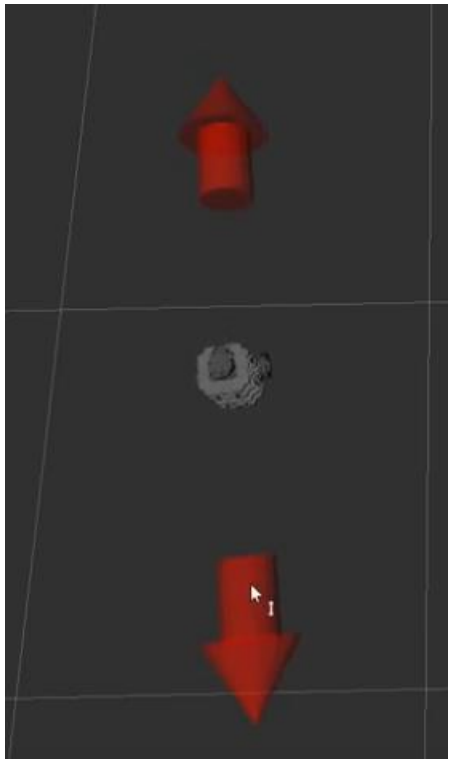
```
$ roslaunch turtlebot3_example
interactive_markers.launch
```

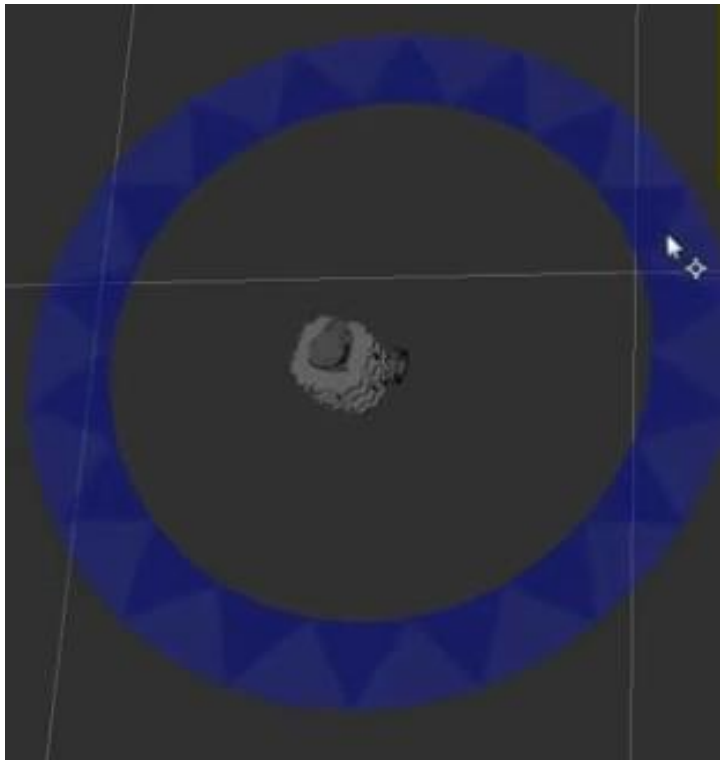
- **On the Remote PC**, open new terminal and type:

```
$ rosrun rviz rviz -d `rospack find
turtlebot3_example`/rviz/turtlebot3_interactive.rviz
```

3. Basic examples

Move using Interactive Markers on RViz; use the Markers to rotate or translate the TB3:





3. Basic examples

Obstacle Detection (using LDS data to move or stop the TB3; stops when it detects obstacle ahead). **Steps:**

- Switch on TB3 and activate Bringup first
- Ensure TB3 has enough space to move around
- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_example
turtlebot3_obstacle.launch
```

- Put an obstacle in front of the TB3 to see if it stops

3. Basic examples

Point Operation (move the TB3 to a point within a 2D space and rotate it); Steps:

- Switch on TB3 and activate Bringup first
- Ensure TB3 has enough space to move around
- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_example
turtlebot3_pointop_key.launch
```

- Type `0.0 0.0 90` in the terminal to represent points x, y and z; z is the rotational angle the TB3 will turn to; **`(0.0, 0.0)` position is the bring-up position**

4. Using Python for TB3

Try the following codes that were used in Gazebo for the previous module, M5:

1. `trajectory.py` **(will not work out as well as seen in simulation; why?)**
2. `laser_data.py`
3. `avoid_obstacle.py`

General Steps to execute python codes for TB3:

1. Switch on TB3 and activate Bringup first
2. Ensure TB3 has enough space to move around
3. **On the Remote PC**, open new terminal and type:

```
$ rosrun autonomous name_of_file.py
```

SLAM

Steps:

- Switch on TB3 and activate Bringup first
- **Ensure TB3 has enough space to move around with ample walls/obstacles around**
- **On the Remote PC**, open new terminal and type the following commands to access TB3 PC:

```
$ ssh ubuntu@192.168.XX.XX
```

You will see in this terminal that you are connected to the pi's terminal

- **On the TB3 PC** (using the linked pi terminal), type:

```
$ roslaunch turtlebot3_bringup
turtlebot3_rpicamera.launch
```

(optional; this will activate the Pi camera)

Steps (cont):

- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_slam
turtlebot3_slam.launch
slam_methods:=gmapping
```

(note that the RViz tool will be automatically executed when you run the above command)

SLAM

Steps (cont):

- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_teleop
turtlebot3_teleop_key.launch
```

- Control the TB3 using the keys w, a, s, d, x
- **Move the robot to explore the area and collect map data**; you need not explore the whole area for now (this is only for practice; you will need to explore extensively for the project later, including all corners)
- **It is important to avoid vigorous movements such as changing the speed too quickly or rotating too fast; I will explain why later**

Steps (cont):

- **On the Remote PC**, open new terminal and type:

```
$ rosrun map_server map_saver -f ~/map_name
```

- This will save the map in the $HOME directory
- We can use this map for Navigation purposes later
- You can change the map name by changing `map_name`

Navigation

Steps:

Part I – Run Navigation Nodes

- Switch on TB3 and activate Bringup first
- **Ensure TB3 is within the map that you have created previously**
- **On the Remote PC**, open new terminal and type:

```
$ roslaunch turtlebot3_navigation
turtlebot3_navigation.launch
map_file:=$HOME/map_name.yaml
```

(note that the RViz tool is automatically executed when you run the above command)

Navigation

Steps (cont):

Part II – Estimate Initial Pose

- **In the RViz application, click on “2D Pose Estimate” button**
- Click on the exact location of the actual robot position in the RViz map AND
- While holding down the left mouse button, drag the green arrow to the direction where the TB3’s front is facing (same as Gazebo example)
- This step helps to calibrate the position and direction of the TB3 within the virtual map space

Navigation

Steps (cont):

Part III – Send Navigation Goal

- **In the RViz application, click on “2D Nav Goal” button**; a very large green arrow will appear

  This green arrow is a marker that can specify the destination of the robot

- Click this arrow at your desired final destination, and drag it to set your desired final orientation of the TB3 (same as Gazebo example)
- The robot will create a path to avoid obstacles to its destination based on the map. Then, the robot moves along the path.
- At this time, even if an obstacle is suddenly detected, the robot moves to the target point avoiding the obstacle

GROUP PROJECT 4

APPLICATION OF SLAM & NAVIGATION OF TB3 WITHIN THE PHYSICAL WORLD

Group Project 4

The use of LIDAR is useful within autonomous vehicles as it is able to detect obstacles for collision avoidance purposes. Its strengths include its abilities to accurately estimate the vehicle's position (localization), to work well in the dark and to efficiently create the estimated map from collected LIDAR data.

For this project, you are to **compare the pros/cons between manual-based (RC100 OR teleop node controller) vehicles and autonomous-based vehicles using LIDAR technology**.

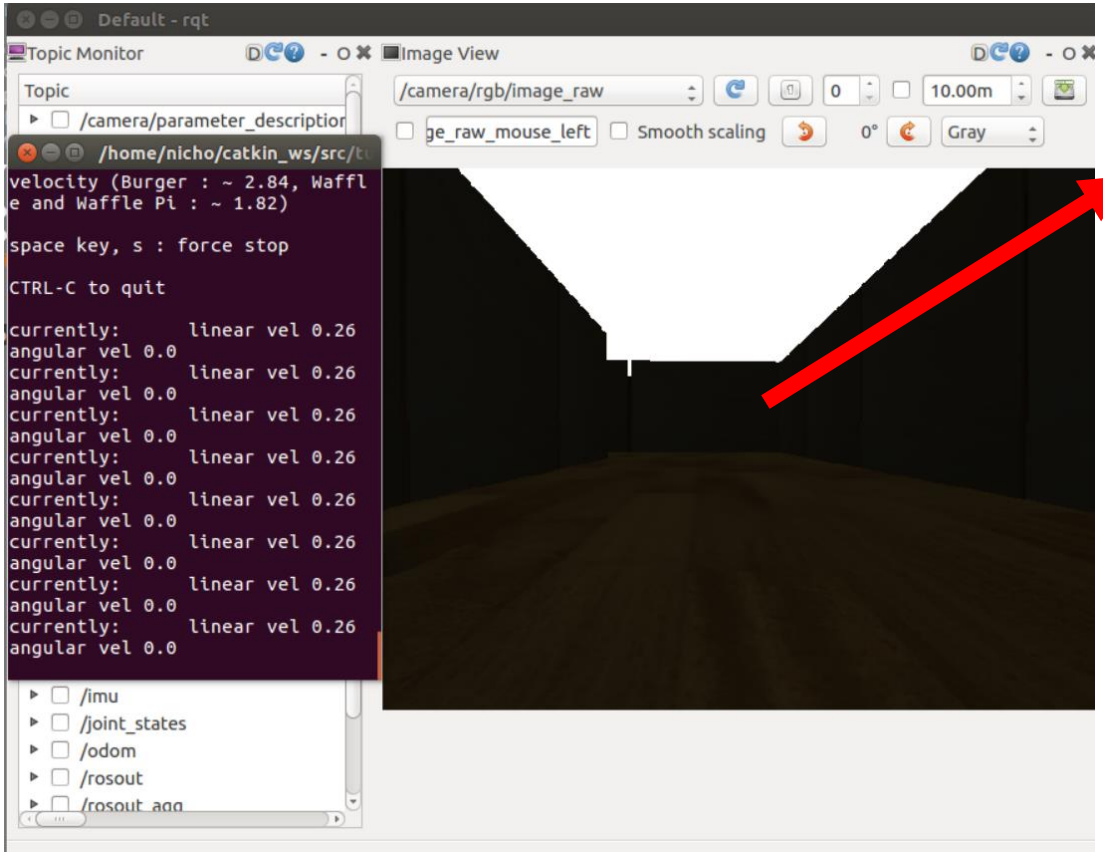
Group Project 4

In groups, you are to:

1. Firstly, try using the **RC100 OR teleop node controller** to remotely navigate the TB3 through the tunnel from the starting point to the desired destination AND orientation. You only can use the camera of the TB3 (in `rqt_image_view`) as your visual guide. Time yourself and reflect on the pros/cons of this method
2. Secondly, using the **SLAM & NAVIGATION methods** that we practiced previously, **configure an autonomous vehicle** that will automatically navigate itself within the tunnel from the starting point to the desired destination AND orientation. Use *roslaunch* and *rospy* to aid you in the navigation node (i.e. take reference from Project 3b). Time yourself and reflect on the pros/cons of this method
3. **Optional: Put random obstacles along the paths of the vehicles during their navigation process** and see what happens. Do it for both methods

Group Project 4

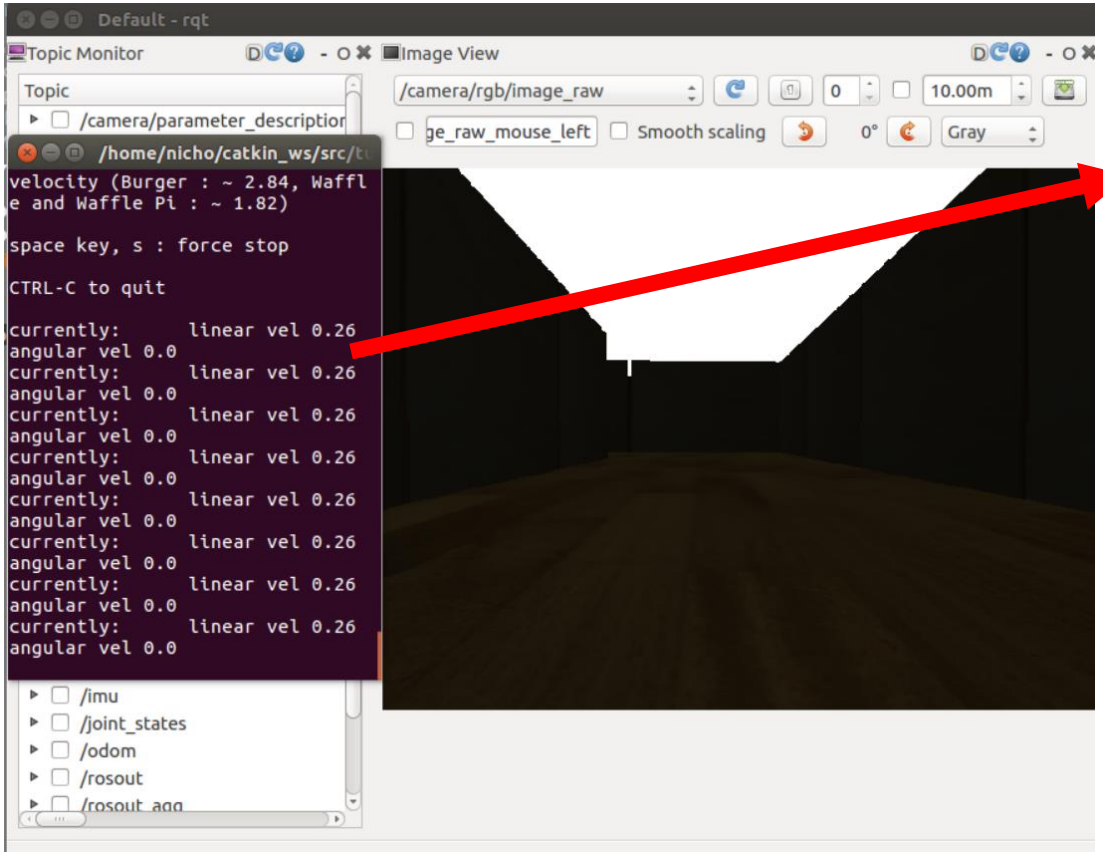
Manual Driving (teleop node):



- To open up Image View, in new terminal, type **`rqt_image_view`**
- Once `rqt_image_view` window is open, select the correct topic: **`/raspicam_node/image/compressed`**

Group Project 4

Manual Driving (teleop node):



To activate teleop node, in new terminal, type command:

```
$ roslaunch
turtlebot3_teleop
turtlebot3_teleop
_key.launch
```

You can use the RC100 controller instead of teleop

Project 4

REMINDER:

You have to **BRINGUP** your TB3 first before you execute any SLAM or NAVIGATION nodes (**refer to README for clearer and detailed instructions**); Note that when BringUp, the poses of the TB3 will all be restarted

Example for NAVIGATION node:

1. Bringup the TB3 (without Manipulator); activate the rpicamera if you are performing Manual Control
2. Execute launch file to execute required tasks:

```
$ roslaunch autonomous Project4.launch
map_file:=$HOME/map_name.yaml
```

Meaning you are only required to type 1 command line to perform the given tasks

Group Project 4

IMPORTANT POINTERS:

1. **You can use the RC100 controller when you doing SLAM but AVOID vigorous movements, especially very sharp turns**
2. **Initial pose using `/odom` data may not be very accurate for actual physical situations** as compared to simulation. **Why???**
   - **For this project, you may want to mark your initial pose.** This initial pose will be where you BringUp the TB3 first before running any SLAM or navigation nodes; the `/odom` data will restart at origin when you BringUp the TB3
3. **Do NOT carry TB3 with your hands while the TB3 is running the BringUp node**. **Why???** If you accidentally do so, you have to carry the TB3 to the initial pose and restart the Bring Up node

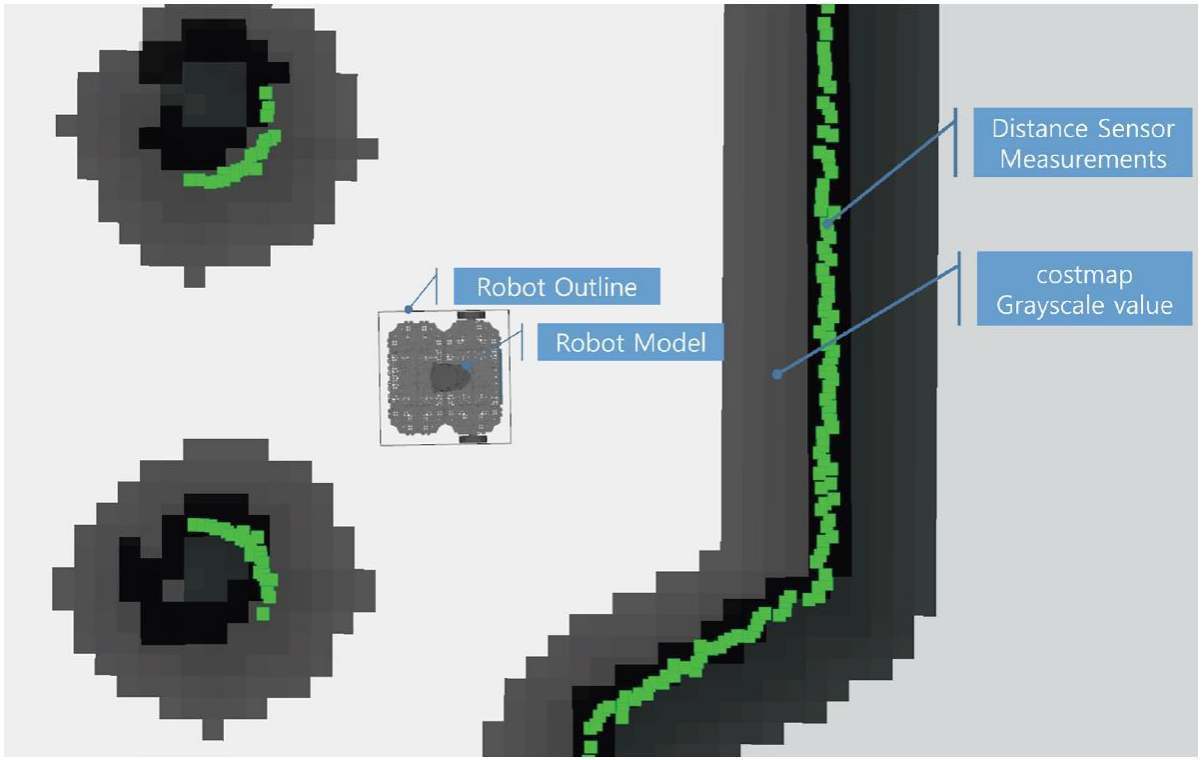
Group Project 4

IMPORTANT POINTERS:

If the given map has narrow corners, you can **fine tune the navigation parameters** to allow your TB3 to maneuverer those narrow spaces (covered in next few slides).

However, **for this project, you do not need to change any navigation parameters. The default parameters will be good enough for the given environment.**

Tuning Guide for Navigation Parameters (Costmap):



You can view the costmap in your RViz application when running the Navigation Node

Changing Costmap Parameters:

File can be found in the navigation package:

`turtlebot3_navigation/param/costmap_common_params_waffle_pi.yaml`

costmap_common_params_waffle_pi.yaml (~/catkin_ws/src/turtlebot3/turtlebot3_navigat

Open Save

```
obstacle_range: 3.0
raytrace_range: 3.5

footprint: [[-0.205, -0.155], [-0.205, 0.155], [0.077, 0.155], [0.077, -0.155]]
#robot_radius: 0.17

#default
#inflation_radius: 1.0
#cost_scaling_factor: 3.0

###### changed parameters ######
inflation_radius: 0.23
cost_scaling_factor: 2.0

map_type: costmap
observation_sources: scan
scan: {sensor_frame: base_scan, data_type: LaserScan, topic: scan, marking:
true, clearing: true}
```

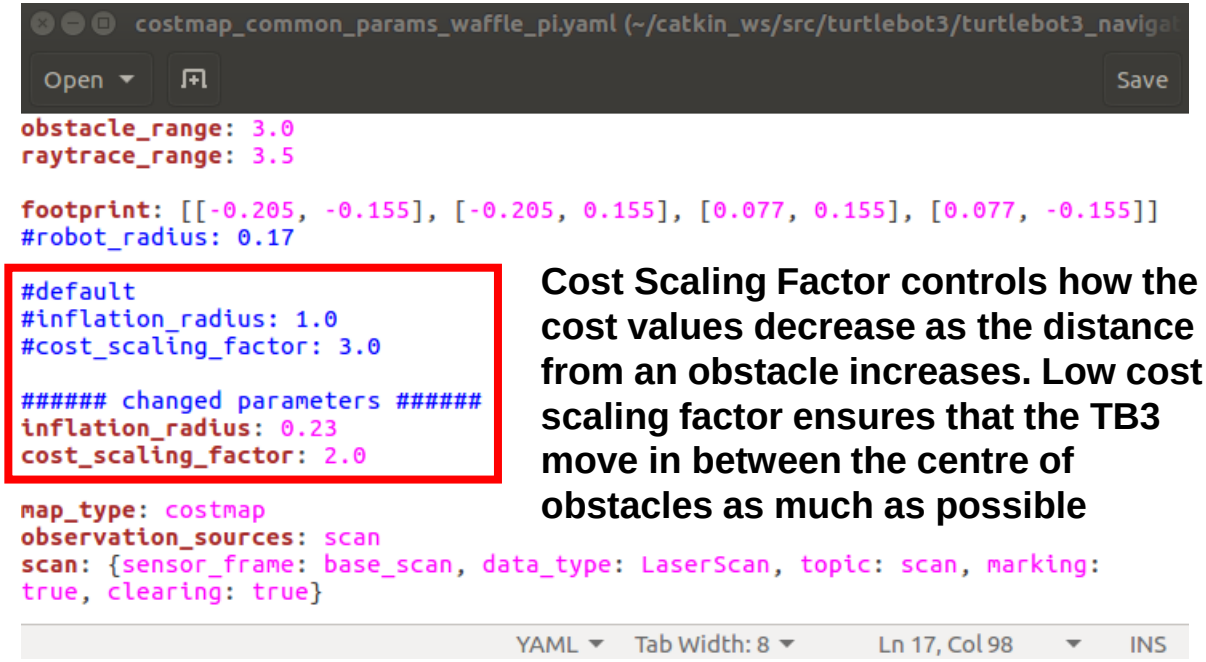
YAML Tab Width: 8 Ln 17, Col 98 INS

Inflation radius serve as a safety buffer around obstacles; Low inflation radius reduce allowable distance between the TB3 and obstacles

Changing Costmap Parameters:

File can be found in the navigation package:

`turtlebot3_navigation/param/costmap_common_params_waffle_pi.yaml`



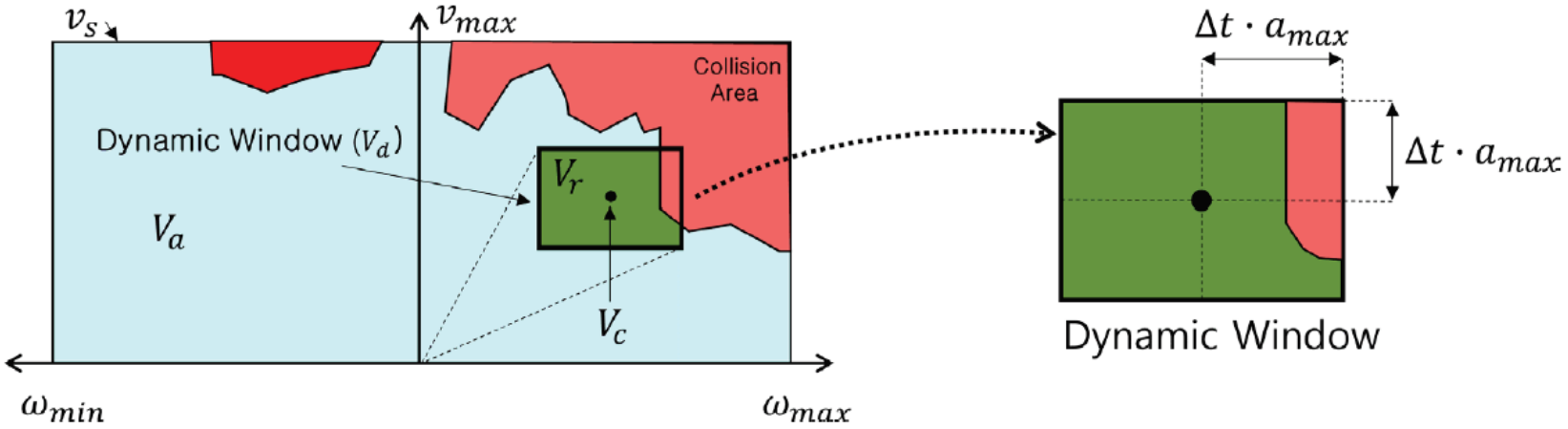
Cost Scaling Factor controls how the cost values decrease as the distance from an obstacle increases. Low cost scaling factor ensures that the TB3 move in between the centre of obstacles as much as possible

Tuning Guide for Navigation Parameters (DWA Local Planner):

- DWA = **Dynamic Window Approach**
- Popular method for **obstacle avoidance planning and avoiding obstacles**
- Method of **selecting a speed that can quickly reach a target point while avoiding obstacles that can possibly collide with the robot in the velocity search space**
- Known for its **superior performance**

DWA Theory (Summary)

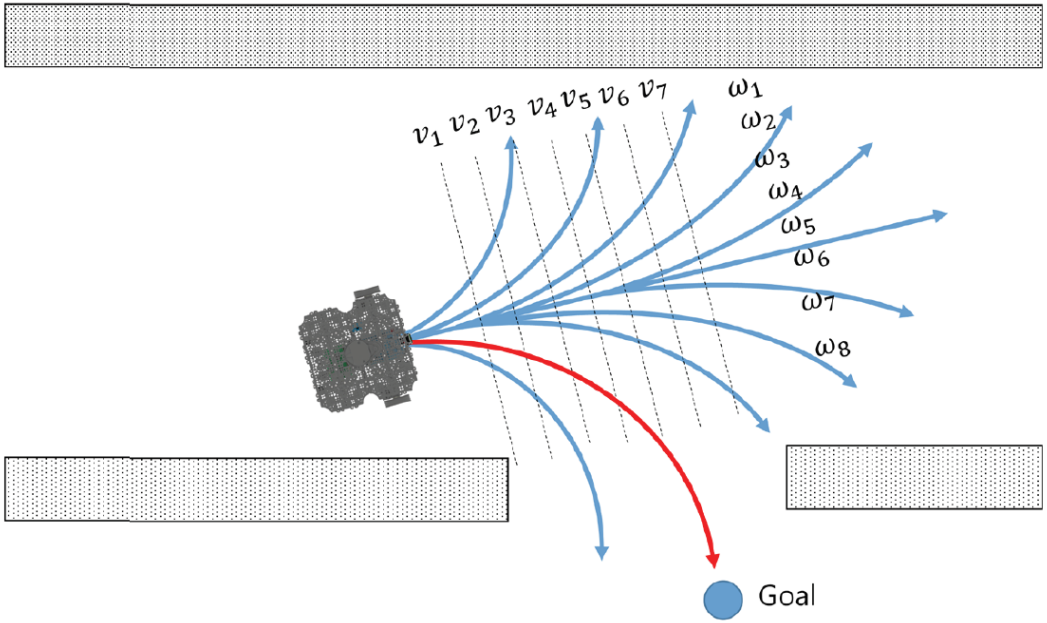
Within the dynamic window, the **objective function *G(v, ω)*** is used to **calculate the translational velocity *v* and the rotational velocity ω** that maximizes the objective function **which considers the direction, velocity and collision of the robot**



Robot's velocity search space and dynamic window

DWA Theory (Summary)

The aim is to find the optimal velocities among various v and ω options to the destination



Translational velocity v and rotational velocity ω

DWA will evaluate multiple potential paths in real-time. With the help of the costmap, it will choose the safest (minimum costs incurred) and most efficient path towards the goal.

Tuning Guide for Navigation Parameters (DWA Local Planner):

Trajectory Scoring Parameters

The cost function used to score each trajectory is in the following form:

```
cost =
  path_distance_bias * (distance to path from the endpoint of the trajectory in meters)
  + goal_distance_bias * (distance to local goal from the endpoint of the trajectory in meters)
  + occdist_scale * (maximum obstacle cost along the trajectory in obstacle cost (0-254))
```

`~<name>/path_distance_bias`

The weighting for how much the controller should stay close to the path it was given

`~<name>/goal_distance_bias`

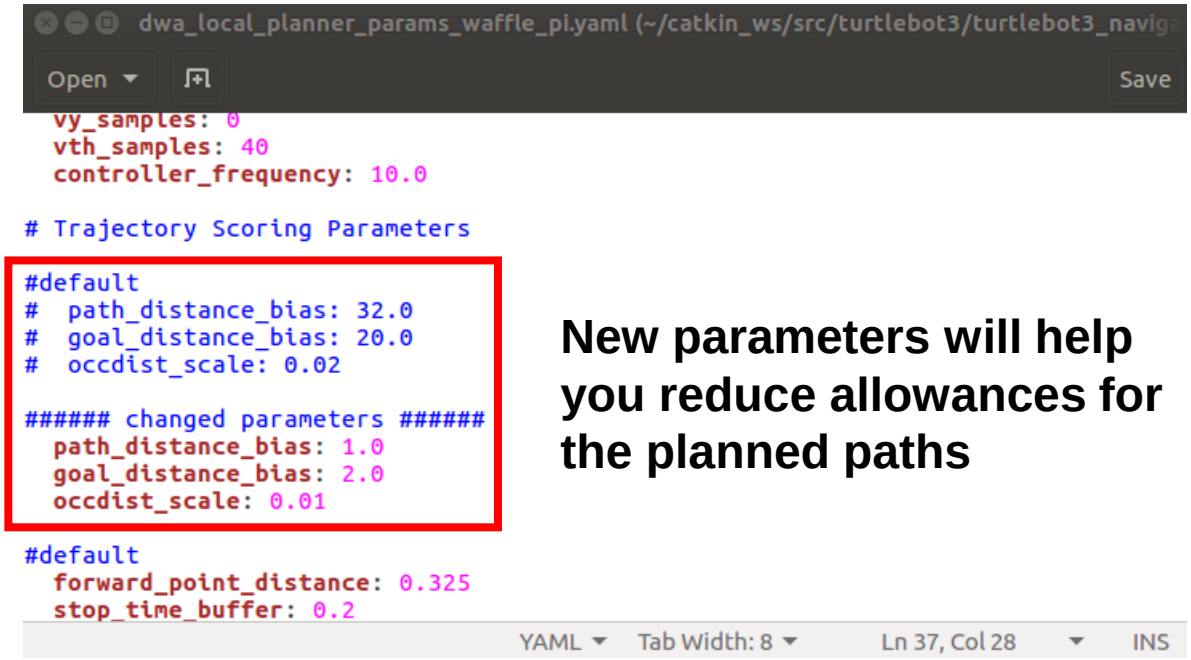
The weighting for how much the controller should attempt to reach its local goal, also controls speed

`~<name>/occdist_scale`

The weighting for how much the controller should attempt to avoid obstacles

Tuning Guide for Navigation Parameters (DWA Local Planner):

File can be found in the navigation package:
`turtlebot3_navigation/param/dwa_local_planner_params_waffle_pi.yaml`



New parameters will help you reduce allowances for the planned paths

Group Project 4

Fill in the comparison table below:

Comparison Metrics	Manual-based (RC100 or teleop controller) vehicles	Autonomous-based vehicles using LIDAR technology
Time taken to complete driving task		
Development time taken (if any)		
Ability to estimate position of vehicle accurately in real-time		
Ability to create virtual, estimated map in real-time		
Ability to continue driving if vision is blocked or when dark		

Group Project 4

4 Items to Submit

(can zip all in one file):

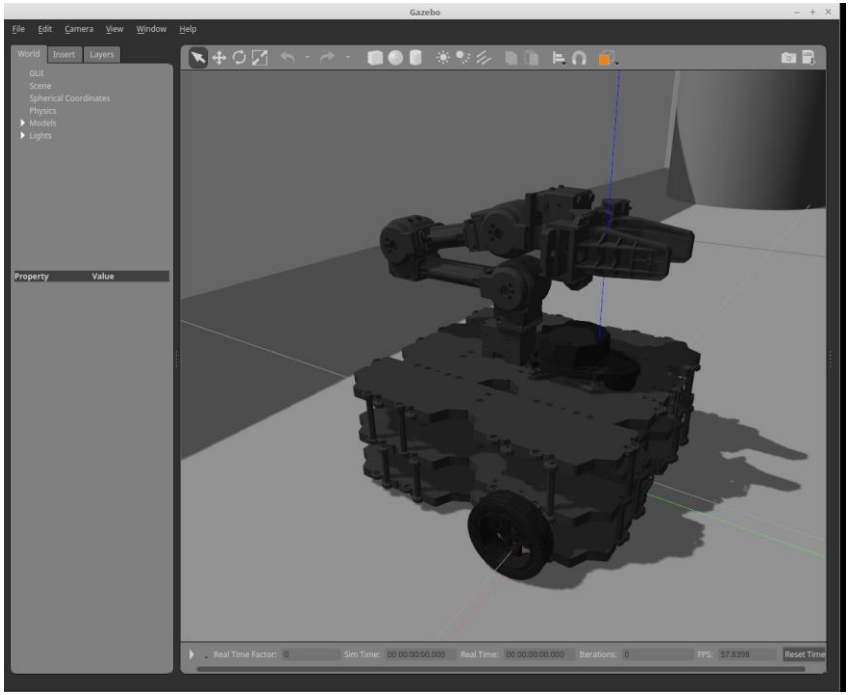
1. `Project4.launch`
2. Other supporting python file(s)
3. Created Map files of the tunnel (both .yaml and .pgm files)
4. Comparison Table (word or PDF accepted)

TURTLEBOT3 WAFFLE PI WITH ARM [VIRTUAL; TO PRACTICE]

Note that the physical TB3_with_OM system does not work well in ROS Noetic. Hence, your practice workshops for TB3_with_OM and Project 5 will be virtual-based instead.

The next few slides are there for your own information only; I will conduct a physical demo (based on ROS Kinetic) to showcase the workshops and Project 5 instead.

Run Gazebo



- Launch TurtleBot3 with arm in Gazebo
- `$ roslaunch turtlebot3_manipulation_gazebo turtlebot3_manipulation_gazebo.launch`
- Click Play button

Run move_group Node

In a new terminal, type the command to use the Moveit feature:

```
$ roslaunch turtlebot3_manipulation_moveit_config move_group.launch
```

If the node is launched successfully, the following message will be printed in the terminal:

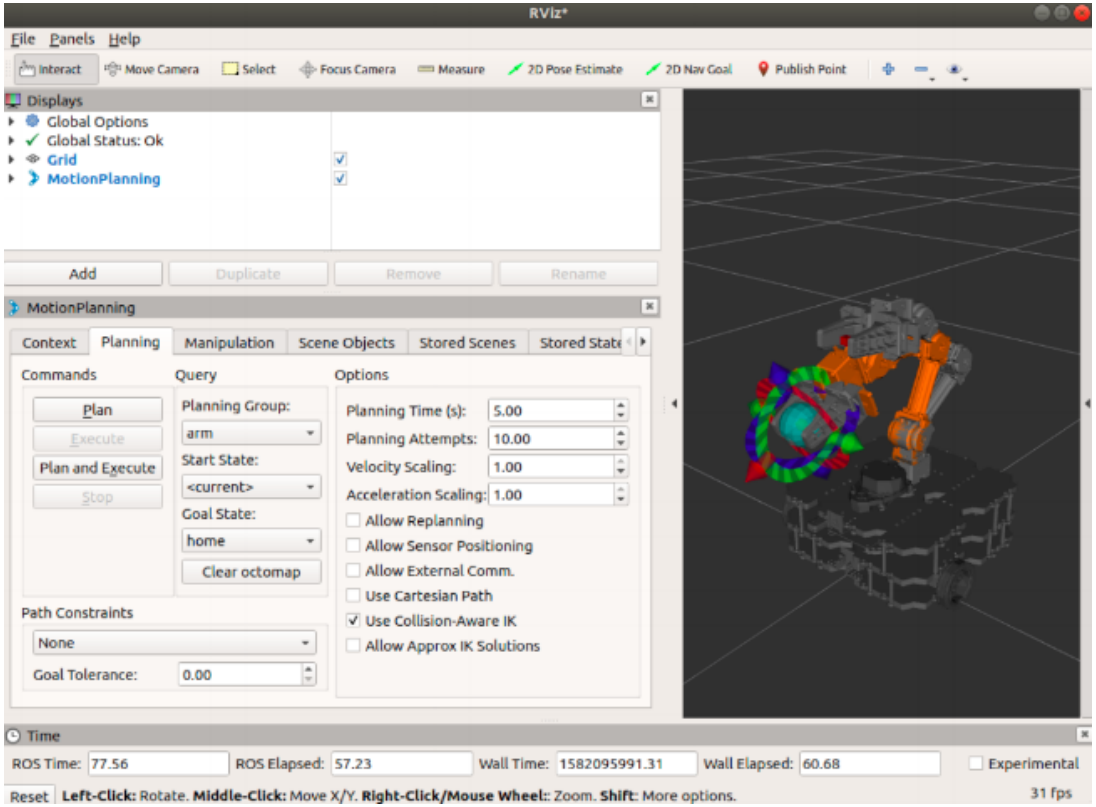
“You can start planning now!”

*****<u>Important:</u> you must run both Gazebo and move_group nodes first before you can control the OM on the TB3**

(a) Control via RViz

In a new terminal, type the command:

```
$ roslaunch turtlebot3_manipulation_moveit_config
moveit_rviz.launch
```



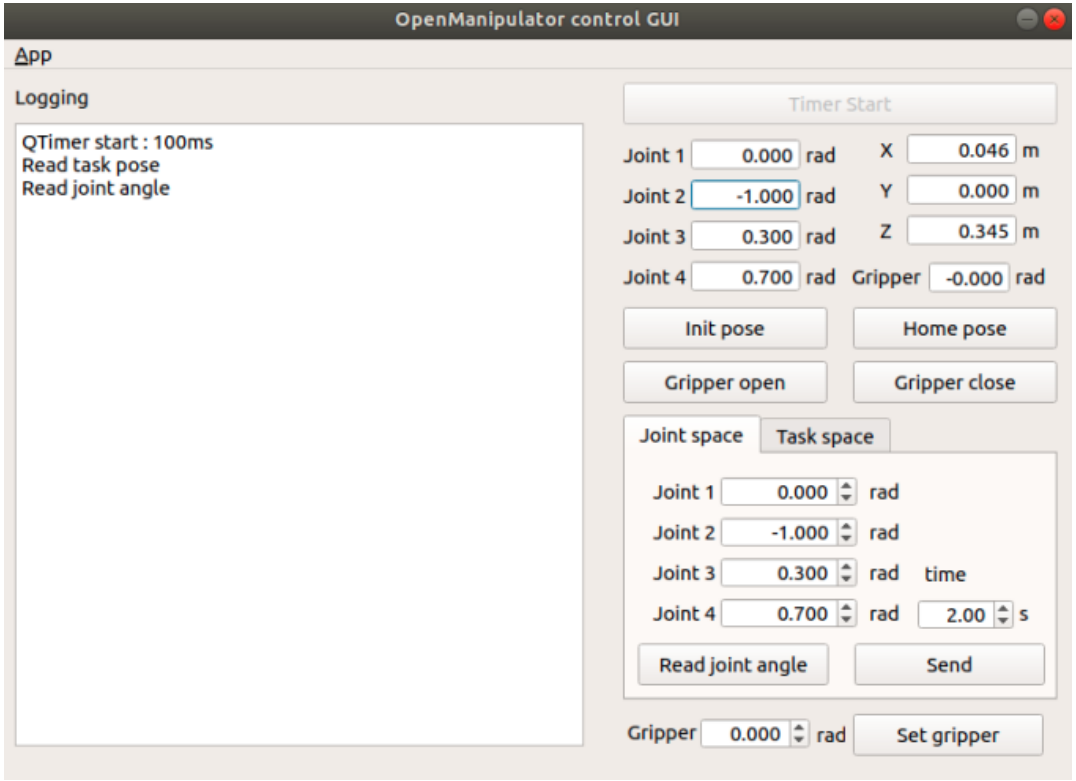
You can control the mounted OM using the Interactive Markers:

- Under MotionPlanning, click on the “Planning” Tab
- Move the Interactive Markers to shift the arm to your desired position
- Click “Plan and Execute” to move the arm

(b) Control via GUI

In a new terminal, type the command:

```
$ roslaunch turtlebot3_manipulation_gui
turtlebot3_manipulation_gui.launch
```



You can control the mounted OM using the GUI:

- **Run Gazebo and the Move Group Node first**
- **Same way of using as the OM only**
- **Task Space Control** and **Joint Space Control**

(c) SLAM and Controlled Navigation

We will now use the following launch file:

`TB3_with_OM.launch`

This edited launch file allows you to use the TB3 world as your map in Gazebo for the TB3 with OM robot

(c) SLAM and Controlled Navigation

For Virtual SLAM (one TB3), 4 Steps; same as TB3 without arm but commands differ slightly (you may skip this process):

Step 1 - Launch the TB3 with arm in the *TB3 World* map in Gazebo

- `$ roslaunch autonomous TB3_with_OM.launch`
- Click Play button

Step 2 - Launch RViz SLAM app in new terminal

- `$ roslaunch turtlebot3_manipulation_slam slam.launch`

(c) SLAM and Controlled Navigation

Step 3 – Launch teleop node in a new terminal:

- `$ roslaunch turtlebot3_teleop turtlebot3_teleop_key.launch`
- Use the keys to make the TB3 explore the area to capture data on the map

Step 4 - Save the Map once Completed in a new terminal:

- `$ rosrun map_server map_saver -f ~/map`

(c) SLAM and Controlled Navigation

For Virtual Controlled Navigation, 2 Steps:

Step 1 - Launch Gazebo in *TB3* World

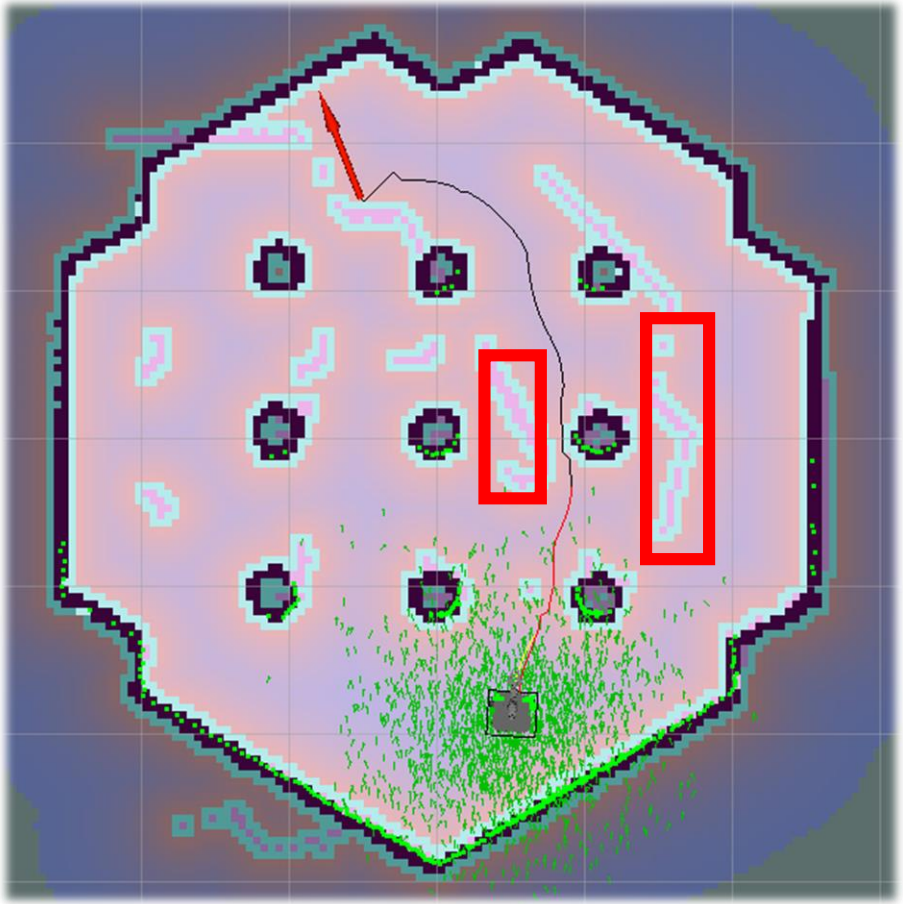
- `$ roslaunch autonomous TB3_with_OM.launch`
- Click Play button

Step 2 - Execute Controlled Navigation in a new terminal

- `$ roslaunch turtlebot3_manipulation_navigation navigation.launch`
- Click on “2D Pose Estimate” and set the correct initial position for the TB3 with arm
- Click on “2D NAV Goal” and set the target destination for the TB3 with arm

(c) SLAM and Controlled Navigation

RViz Navigation in the *TB3 World* map:



- **RECAP:** Due to the wrong initial pose after launch due to default settings, there will be unwanted cost maps after you have performed the initial pose
- Do remember to get rid of these unwanted cost maps before performing the navigation
- **Rotating and/or Moving the robot back and forth a bit first with teleop node**

(d) Rospy to control OM

For TB3_with_OM robot model, the system is created as such that **you cannot control the OM with messages (i.e. service, publish)**. Instead, you **have to control with Move Group nodes**. You can write a python file to control the OM with **MoveIt interface:**

- Open terminal and type

  ```
  $ rosrun autonomous OM_moveit.py
  ```

- The OM will move to a point determined by the joint angles. To alter these joint angles, open the python file, change the values for the following variables; under the sub-functions *arm_joints()*

  ```
  joint_goal[X]
  ```

- To alter the gripper angle, change the value for the following variable (-0.01 for fully close and 0.01 for fully open); under the sub-functions *gripper_open/close()*

  ```
  joint_grip[0]
  ```

(d) Rospy to control OM

`OM_moveit.py` (imports and Class):

```
import sys
import copy
import rospy
import moveit_commander
import moveit_msgs.msg
import geometry_msgs.msg
from math import pi
from std_msgs.msg import String
from moveit_commander.conversions import pose_to_list
```

Note if you cant execute the python file, you have to give execution permissions to it by typing:

```
$ chmod +x name_of_the_file.py
```

```
def all_close(goal, actual, tolerance):
  """
  Convenience method for testing if a list of values are within a tolerance
another list
  @param: goal       A list of floats, a Pose or a PoseStamped
  @param: actual     A list of floats, a Pose or a PoseStamped
  @param: tolerance  A float
  @returns: bool
  """
  all_equal = True
  if type(goal) is list:
    for index in range(len(goal)):
      if abs(actual[index] - goal[index]) > tolerance:
        return False

  elif type(goal) is geometry_msgs.msg.PoseStamped:
    return all_close(goal.pose, actual.pose, tolerance)

  elif type(goal) is geometry_msgs.msg.Pose:
    return all_close(pose_to_list(goal), pose_to_list(actual), tolerance)

  return True
```

```
class MoveGroupPythonIntefaceTutorial(object):
  """MoveGroupPythonIntefaceTutorial"""
  def __init__(self):
    super(MoveGroupPythonIntefaceTutorial, self).__init__()

    ## First initialize `moveit_commander`_ and a `rospy`_ node:
    moveit_commander.roscpp_initialize(sys.argv)
```

(d) Rospy to control OM

`OM_moveit.py` (arm_joints1 sub function):

```
def arm_joints1(self):
  # Copy class variables to local variables to make the web tutorials more clear.
  # In practice, you should use the class variables directly unless you have a good
  # reason not to.
  group = self.group

  ## Planning to a Joint Goal
  # We can get the joint values from the group and adjust some of the values:
  joint_goal = group.get_current_joint_values()
  joint_goal[0] = 0
  joint_goal[1] = 0
  joint_goal[2] = 0
  joint_goal[3] = 0

  # The go command can be called with joint values, poses, or without any
  # parameters if you have already set the pose or joint target for the group
  group.go(joint_goal, wait=True)

  # Calling ``stop()`` ensures that there is no residual movement
  group.stop()

  ## END_SUB_TUTORIAL

  # For testing:
  # Note that since this section of code will not be included in the tutorials
  # we use the class variable rather than the copied state variable
  current_joints = self.group.get_current_joint_values()
  return all_close(joint_goal, current_joints, 0.01)
```

(d) Rospy to control OM

`OM_moveit.py` (gripper_close sub function):

```
def gripper_close(self):

  grip = self.grip

  joint_grip = grip.get_current_joint_values()
  joint_grip[0] = -0.01

  grip.go(joint_grip, wait=True)

  grip.stop()

  current_grip = self.grip.get_current_joint_values()
  return all_close(joint_grip, current_grip, 0.01)
```

(d) Rospy to control OM

`OM_moveit.py` (main function):

```
def main():
  try:
    print "============ Setting up the moveit_commander ..."
    #raw_input()
    tutorial = MoveGroupPythonIntefaceTutorial()

    print "============ Execute movement using 1st joint state goal ..."
    #raw_input()
    tutorial.arm_joints1()
    time.sleep(7)

    print "============ Execute gripper open ..."
    #raw_input()
    tutorial.gripper_open()
    time.sleep(3)

    print "============ Execute movement using 2nd joint state goal ..."
    #raw_input()
    tutorial.arm_joints2()
    time.sleep(7)

    print "============ Execute gripper close ..."
    #raw_input()
    tutorial.gripper_close()
    time.sleep(3)

    print "============ Python tutorial demo complete!"
  except rospy.ROSInterruptException:
    return
  except KeyboardInterrupt:
    return
```

(d) Rospy to control OM

Try with a different python code:

```
$ rosrun autonomous OM_DEMO.py
```

Similar to what was taught previously, you can **control the mounted OM using python codes**:

- Change the values for the following variables; under the sub-functions *arm_joints1/2()*

  `joint_goal[X]`

- Change the value for the following variable; under the sub-functions *gripper_open/close()*

  `joint_grip[0]`

(e) Pick, Move & Place Example

Procedures:

1. Load TB3 with OM in TB3 World in Gazebo

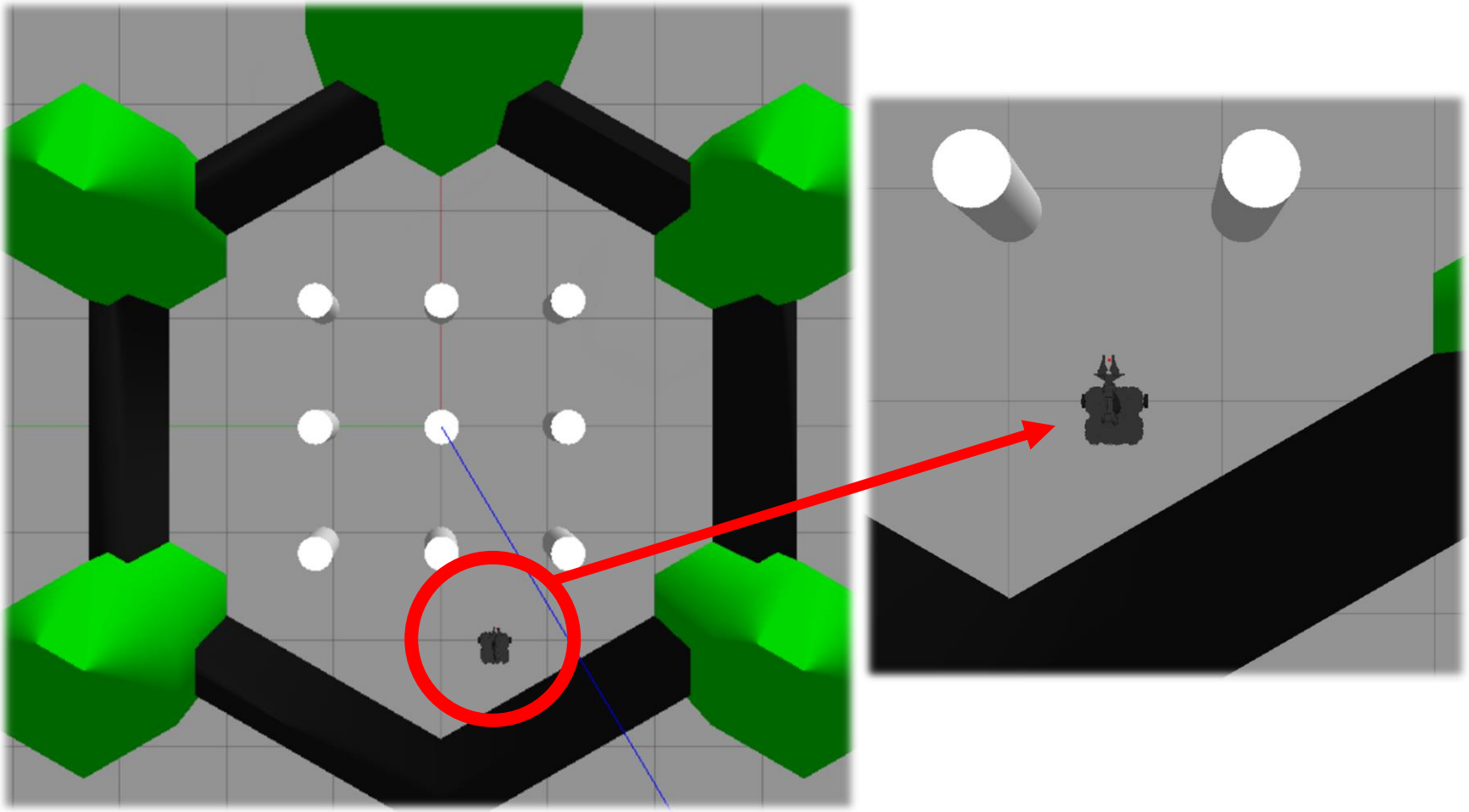
```
$ roslaunch autonomous TB3_with_OM.launch
```

2. Run launch file example to **activate OM control (via move_group)**, to **activate the navigation node**, and to **activate the pick_move_place node**, which make OM “pick” first, after which move TB3 to a certain location, and lastly to make OM “place”

```
$ roslaunch autonomous pick_move_place.launch
```

(e) Pick, Move & Place Example

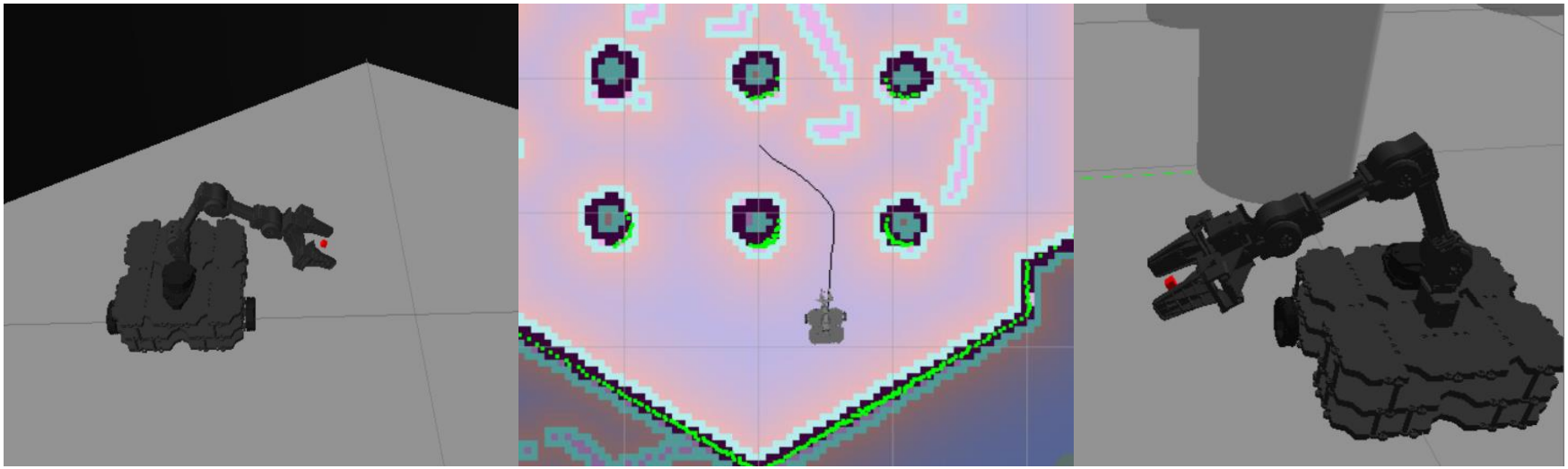
1. Load TB3 with OM in TB3 World in Gazebo:



(e) Pick, Move & Place Example

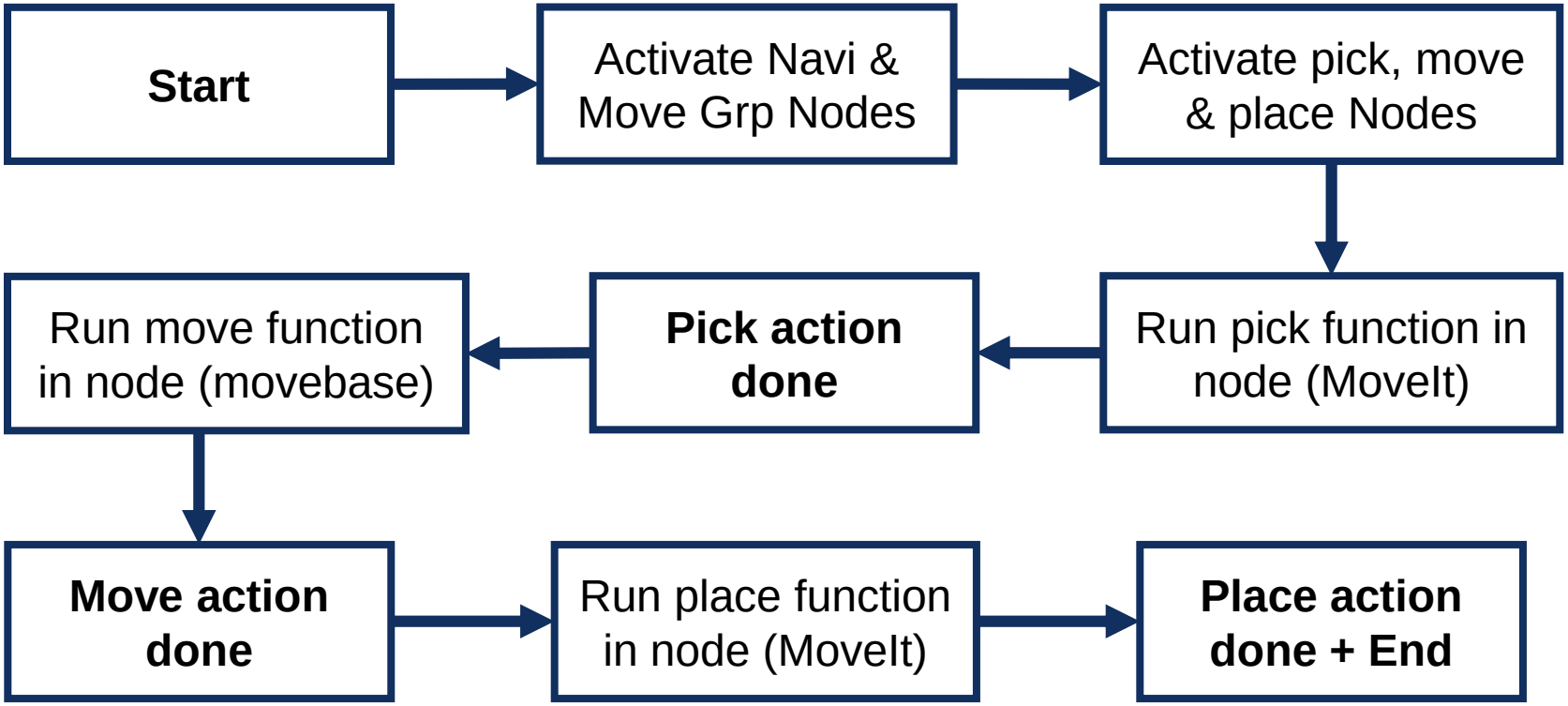
2. Run launch file example to “Pick”, Move and “Place”:

“Pick” Move “Place”

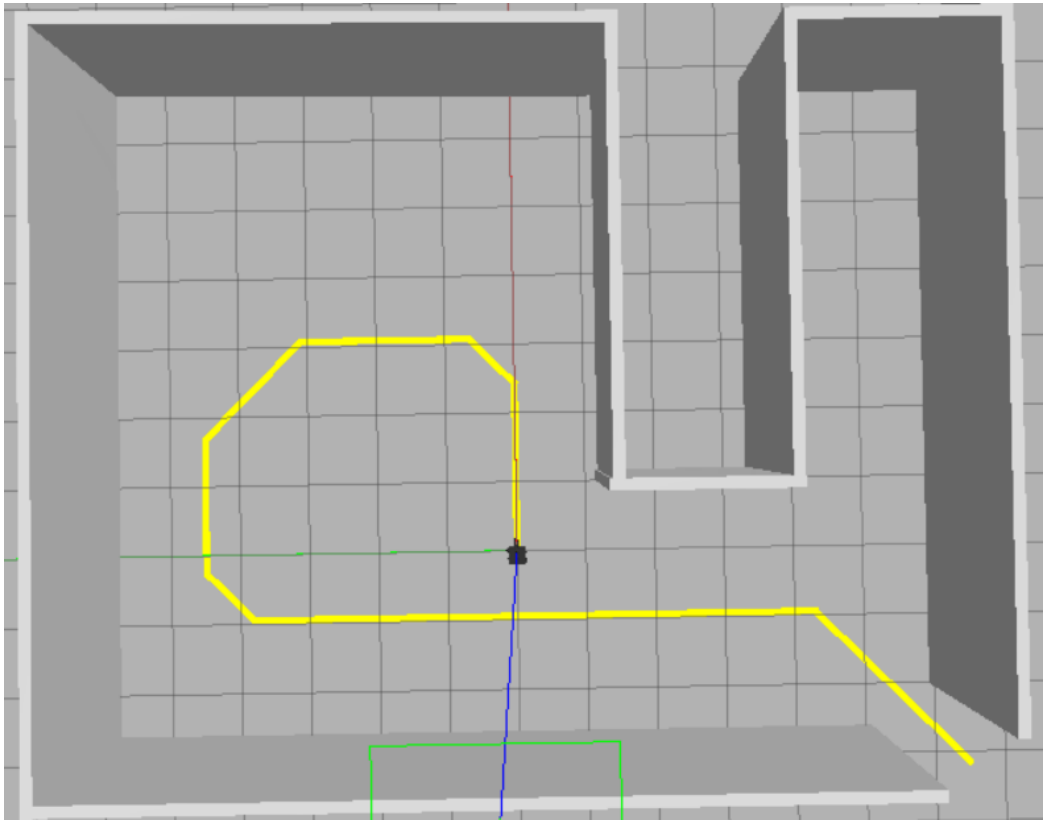


(e) Pick, Move & Place Example

Block Diagram Representation of Algorithm:



(f) Machine Vision



- **TB3 with OM** robot example in Gazebo
- Aim of this exercise is for the robot to **track and follow the yellow line**
- **We can also do this in real life** (i.e. physical TB3 with physical yellow lines); to be shown in demo

(f) Line Follower using MV Example

Procedures:

1. Load TB3 with OM in line.world in Gazebo

   [line2.launch, as compared to line.launch, is based on a slightly different map with shorter yellow lines; to save time]

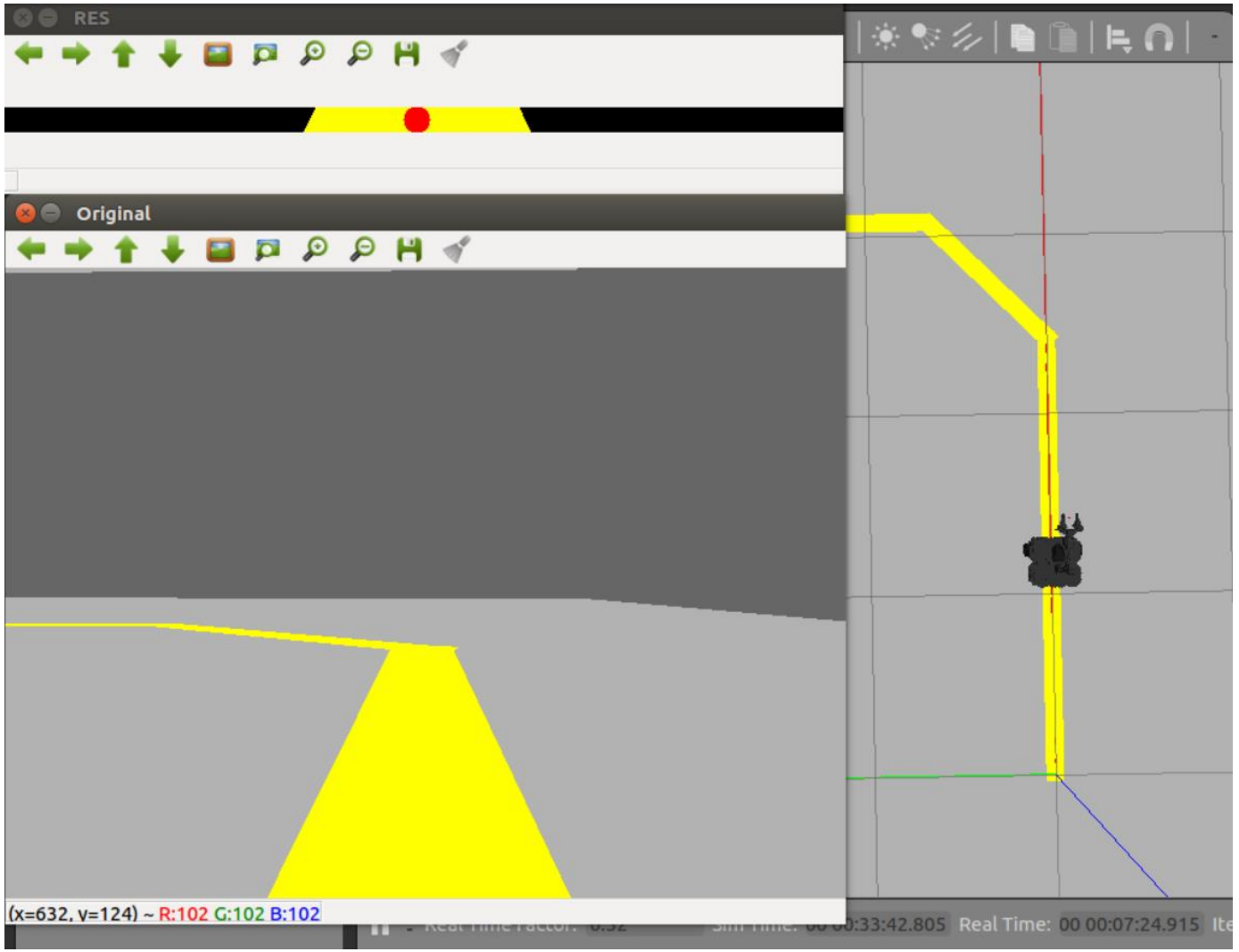
   ```
   $ roslaunch autonomous line2.launch
   ```

2. Run node example to utilize OpenCV to detect the yellow line and make the TB3 follow it

   ```
   $ rosrun autonomous follow_line2.py
   ```

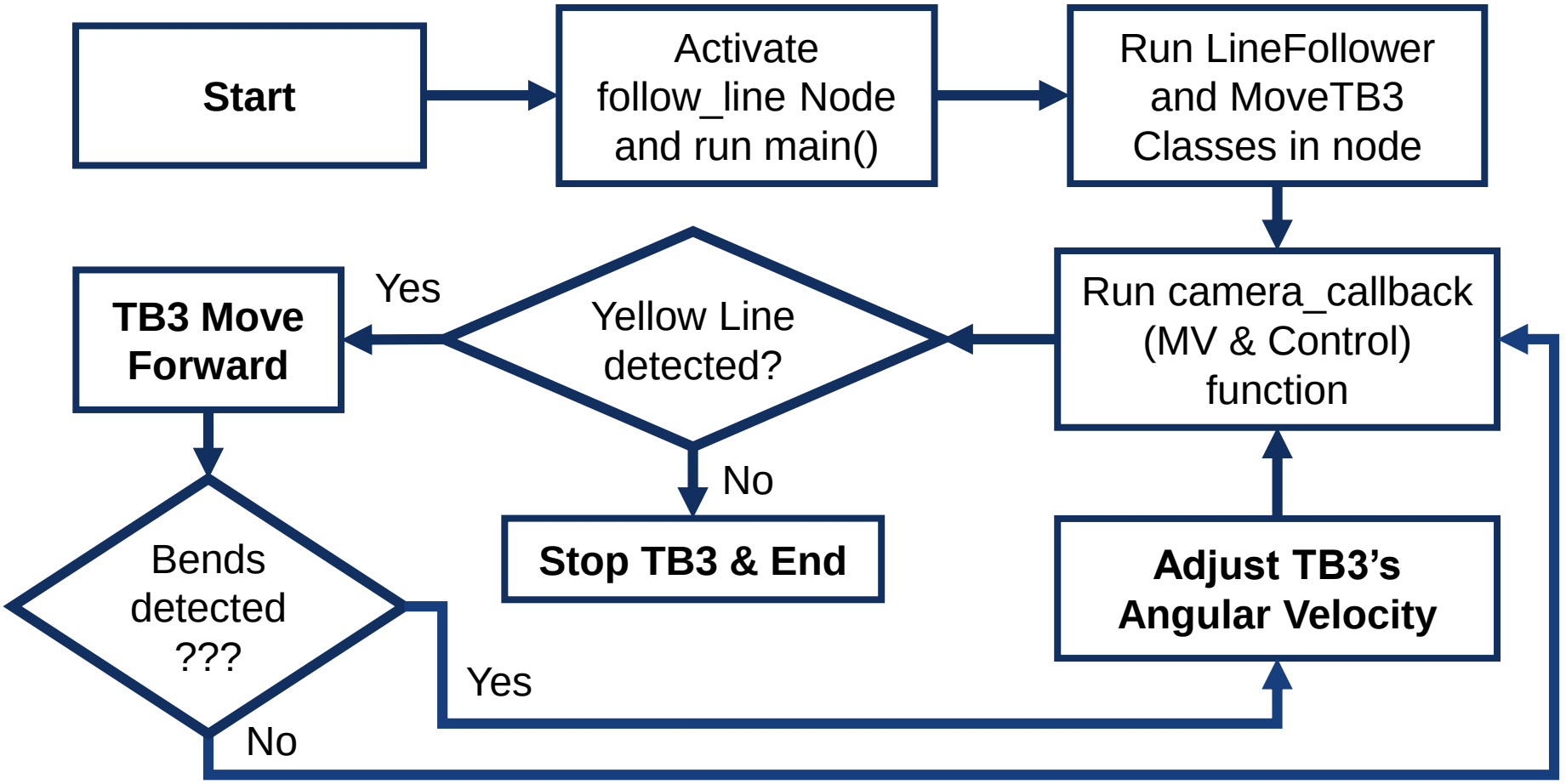
3. Examine the follow_line2.py file

(f) Line Follower using MV Example



(f) Line Follower using MV Example

Block Diagram Representation of Algorithm:



GROUP PROJECT 5

APPLICATION OF MACHINE VISION & MANIPULATOR OF TB3 WITHIN THE PHYSICAL WORLD

Group Project 5

The use of LIDAR has been demonstrated in the previous project. For this project, we will **explore the advantage of using a RGB camera** instead of the LIDAR for perception purposes to guide the TB3 from one location to another with the help of yellow lines.

We will also **explore the advantage of using a manipulator**. The use of manipulators in conjunction with vehicles is expected to increase the versatility of the autonomous system to operate functionalities of both arm and vehicle, which is useful in many applications.

You can **use the same layout that you have built from the previous exercise for this project**. **The goal is to "pick" an item from the startpoint, move the TB3 base (together with the arm and "item") to the endpoint ONLY with the help of the RGB camera, and "place" the item at the endpoint.**

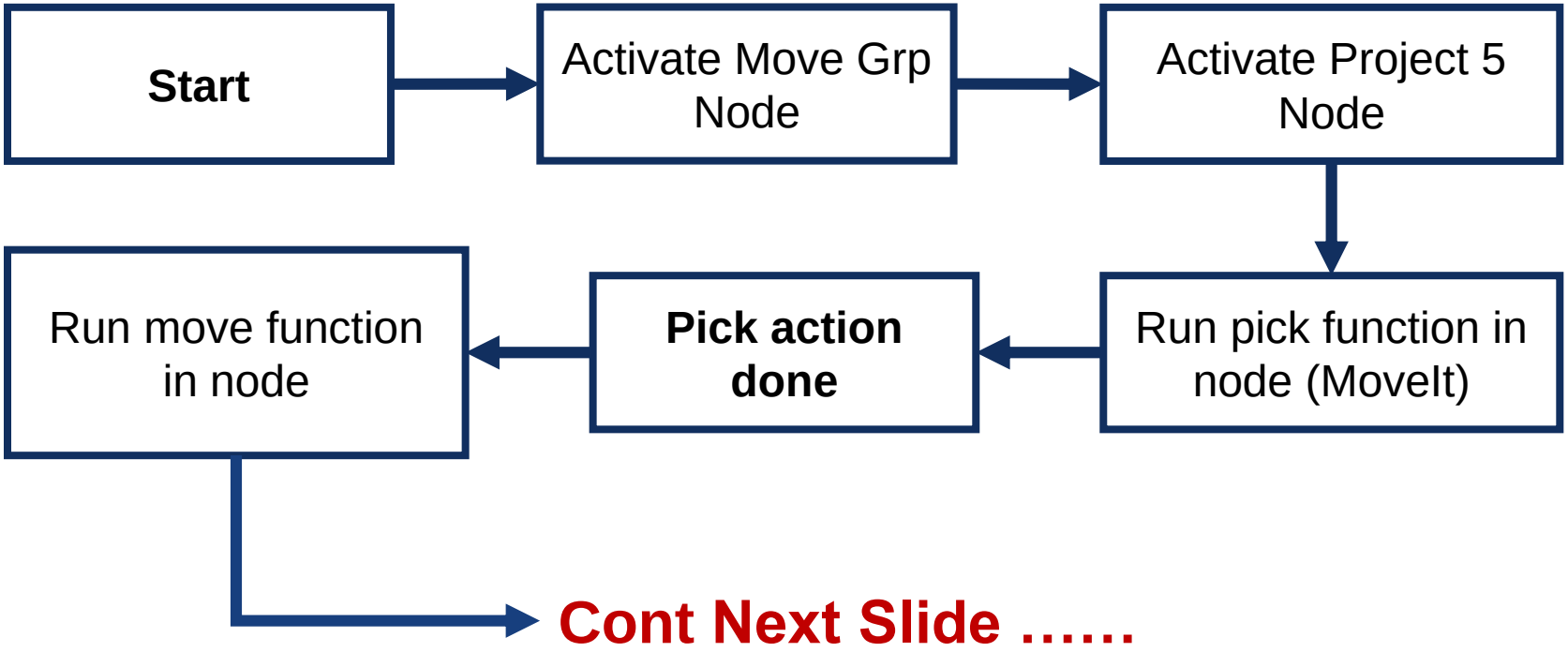
Group Project 5

In groups, you are to write a launch file that:

1. **Activate the MANIPULATION node** (i.e. move_group node) to get ready the OM for use
2. **Use the OM to "pick" the item from startpoint**; assume this action remains the same as the "pick, move, place" example in M5
3. **Bring the TB3 with OM (together with the "item") to the endpoint ONLY with the help of the RGB camera**
4. **Use the OM to "place" the item at the endpoint**; assume this action remains the same as the "pick, move, place" example in M5

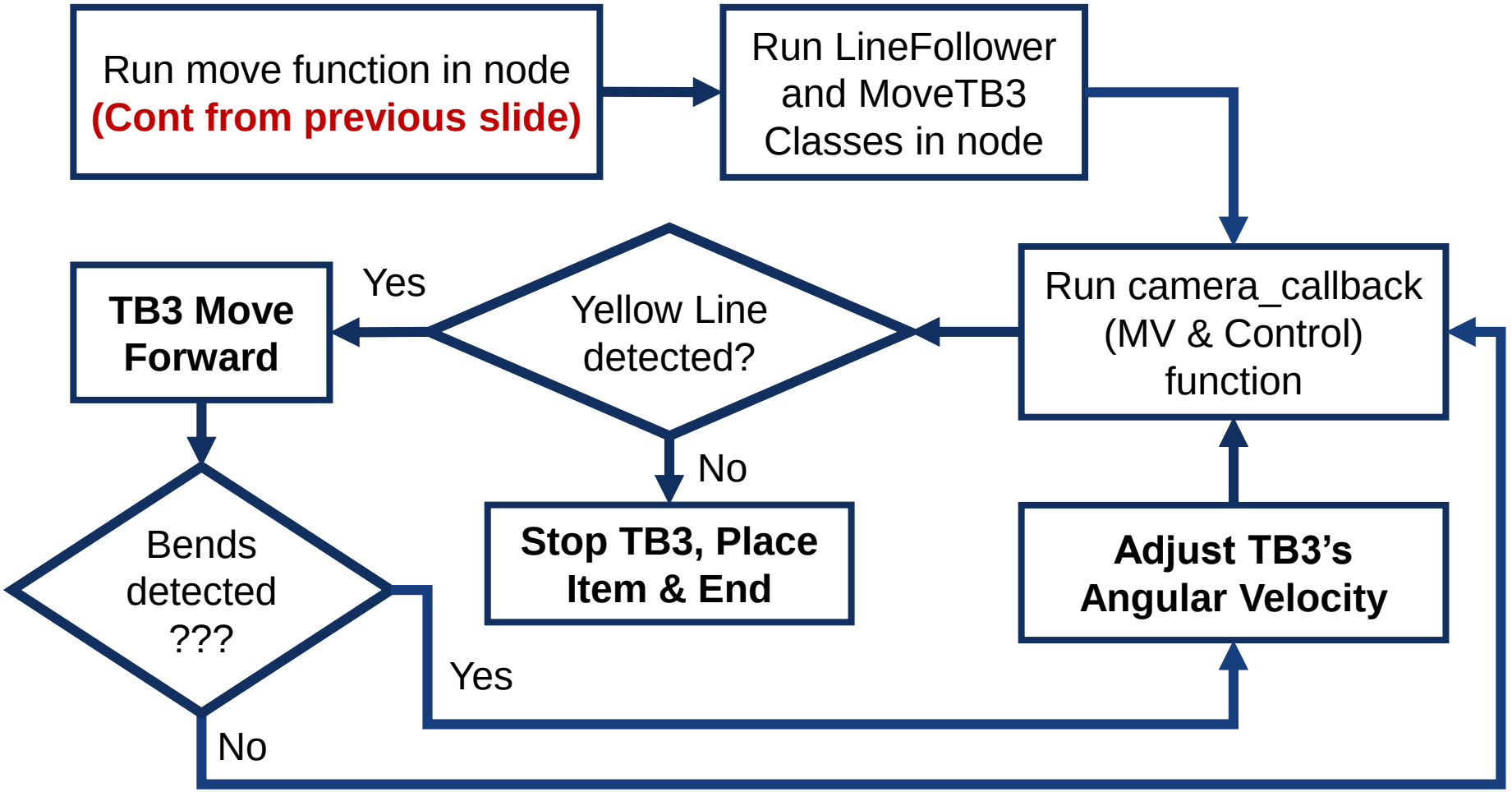
Group Project 5

Block Diagram Representation of Algorithm:



Group Project 5

Block Diagram Representation of Algorithm:



Group Project 5

REMINDER [FYI below instructions are only applicable for physical robot; skip this]:

You have to **BRINGUP** your TB3 with OM (**2 BRINGUPs** to execute) first before you launch the launch file, `Project5.launch` (**refer to README for clearer and detailed instructions**)

Example:

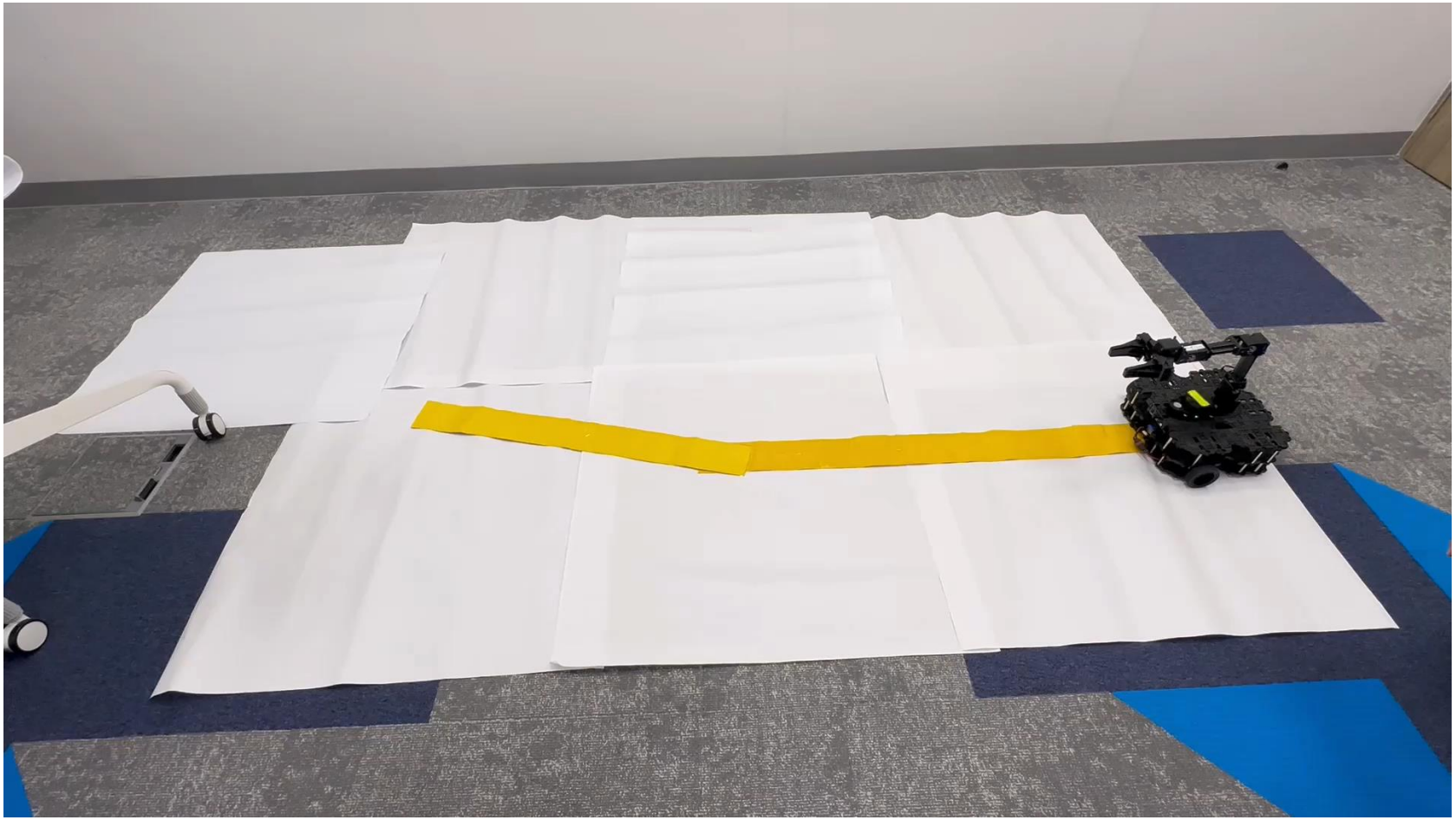
1. BringUp the TB3 (with OM), activate the rpicamera (important step for this project!), transform image to RAW, BringUp the OM (with TB3)
2. Execute launch file to execute required tasks:

```
$ roslaunch autonomous Project5.launch
```

Meaning you are only required to type 1 command line to perform the given tasks

Group Project 5

DEMO VIDEO on Physical Robot (ROS Kinetic):



Group Project 5

Reflect & answer the questions below:

1. What are the advantages of utilizing RGB cameras in autonomous systems as compared to the LIDAR? Compare in terms of your observations from P4 and P5
2. What are the advantages of utilizing manipulators in autonomous vehicles or the like?

Group Project 5

3 Items to Submit (can zip all in one file):

1. `Project5.launch`
2. Other supporting python file(s)
3. Reflection on P5 (word or PDF accepted)

Please upload all your works [Project 4 & 5 zipped together] in CANVAS → Assignments → ARV Workshop 4 Submission

(Each representative per group to submit)

End of Module 6

APPENDIX

TURTLEBOT3 WAFFLE PI WITH ARM [PHYSICAL; FYI ONLY]

Note that the physical TB3_with_OM system does not work well in ROS Noetic. Hence, your practice workshops for TB3_with_OM and Project 5 will be virtual-based instead.

The next few slides are there for your own information only; I will conduct a physical demo (based on ROS Kinetic) to showcase the workshops and Project 5 instead.

Manipulation

OpenCR Setup (do it ONCE!):

1. On the Remote PC, open new terminal and type the following commands to access TB3 PC:
   - `$ ssh ubuntu@192.168.XX.XX`
2. On the TB3 PC, type the following commands in order to upload the firmware to the OpenCR (this will factor in the Open Manipulator arm):
   - `$ export OPENCR_PORT=/dev/ttyACM0`
   - `$ export OPENCR_MODEL=om_with_tb3`
   - `$ rm -rf ./opencr_update.tar.bz2`
   - `$ wget https://github.com/ROBOTIS-GIT/OpenCR-Binaries/raw/master/turtlebot3/ROS1/latest/opencr_update.tar.bz2`
   - `$ tar -xvf opencr_update.tar.bz2`
   - `$ cd ./opencr_update && ./update.sh $OPENCR_PORT $OPENCR_MODEL.opencr && cd ..`

OpenCR Setup (do it ONCE!):

The following will appear on the terminal:

```
[OK] Open port            : /dev/ttyACM0
[  ]
[  ] Board Name           : OpenCR R1.0
[  ] Board Ver            : 0x17020800
[  ] Board Rev            : 0x00000000
[OK] flash_erase          : 0.93s
[OK] flash_write          : 1.23s
[OK] CRC Check            : 119909C 119909C , 0.006000 sec
[OK] Download
[OK] jump_to_fw
```

When firmware upload is completed successfully, `jump_to_fw` text string will be printed on the terminal.

You will also notice that the OM will be raised up automatically when this setup is completed.

Manipulation (TB3)

Bringup for TB3 (with OM):

1. **On the Remote PC**, run roscore (**Important: do NOT run roscore under the TB3 PC!!!**)

   ```
   $ roscore
   ```

2. **On the Remote PC**, open new terminal and type the following commands to **access TB3 PC**:
   - `$ ssh ubuntu@192.168.XX.XX`
3. **On the TB3 PC**, **run Bringup node for TB3, and start rosserial and LDS sensor** using following command:
   - `$ roslaunch turtlebot3_bringup turtlebot3_robot.launch`
4. **On the TB3 PC**, **run the raspicam node for camera functions (OPTIONAL)**
   - `$ roslaunch turtlebot3_bringup turtlebot3_rpicamera.launch`

Manipulation (TB3)

SLAM for TB3 with OM:

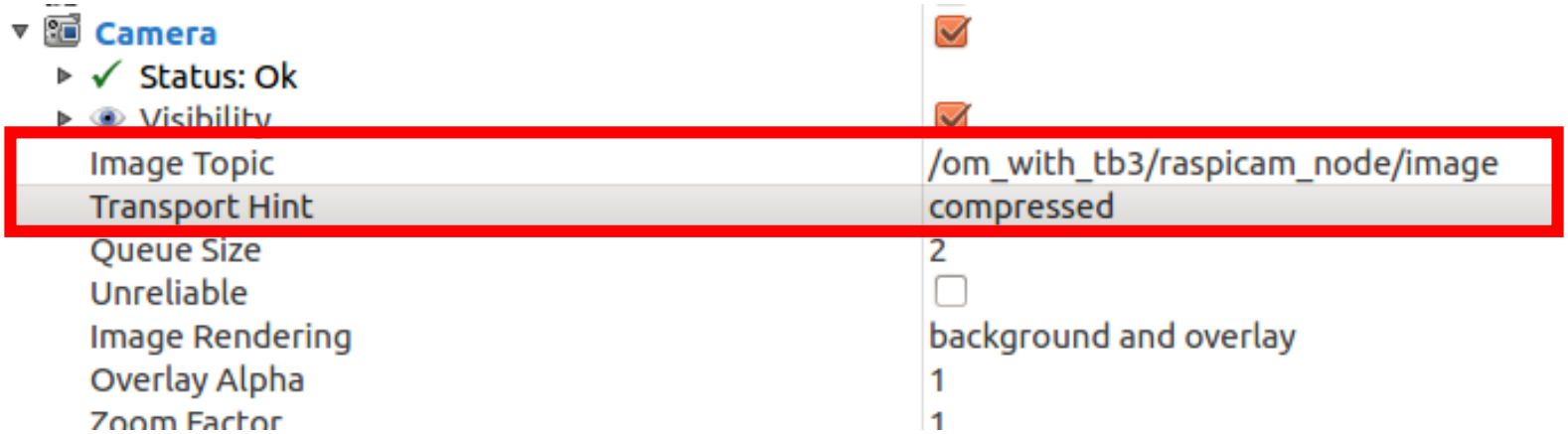
You may skip the SLAM and NAVIGATION sections as they have been already done previously

1. Switch on TB3 and **activate Bringup (for TB3 with OM) first**
2. **Ensure TB3 has enough space to move around with ample walls/obstacles around**
3. **On the Remote PC, launch SLAM node:**
   - `$ roslaunch turtlebot3_manipulation_slam slam.launch`

Manipulation (TB3)

SLAM for TB3 with OM:

4. On the **RViz display settings** (left side), configure the following to enable camera; under *Camera*,
   a) Change topic name to `/om_with_tb3/raspicam_node/image` (if this cannot work, try `/raspicam_node/image`; check `$ rostopic list` to be sure!)
   b) Change Transport Hint to `compressed`



Note that for this to work, you have to run the raspicam node first

SLAM for TB3 with OM:

5. On the Remote PC, launch teleop node and move around to collect map data:
   - `$ roslaunch turtlebot3_teleop turtlebot3_teleop_key.launch`
6. On the Remote PC, launch map_saver node to save the explored map:
   - `$ rosrun map_server map_saver -f ~/map`

Manipulation (TB3)

Navigation for TB3 with OM:

1. Switch on TB3 and **activate Bringup first**
2. **Ensure TB3 is within the relevant area (which you have created a map out of previously)**
3. **On the Remote PC**, open new terminal and **launch the navigation node:**
   - `$ roslaunch turtlebot3_manipulation_navigation navigation.launch`
4. Calibrate the position and direction of the TB3 within the virtual map space in the RViz application using the **"2D Pose Estimate"** button (same as navigation for TB3)
5. Configure the desired final destination and orientation of the TB3 in the RViz application using the **"2D Nav Goal"** button (same as navigation for TB3); the OM with TB3 will respond according to these preset data

Bringup for OM (with TB3):

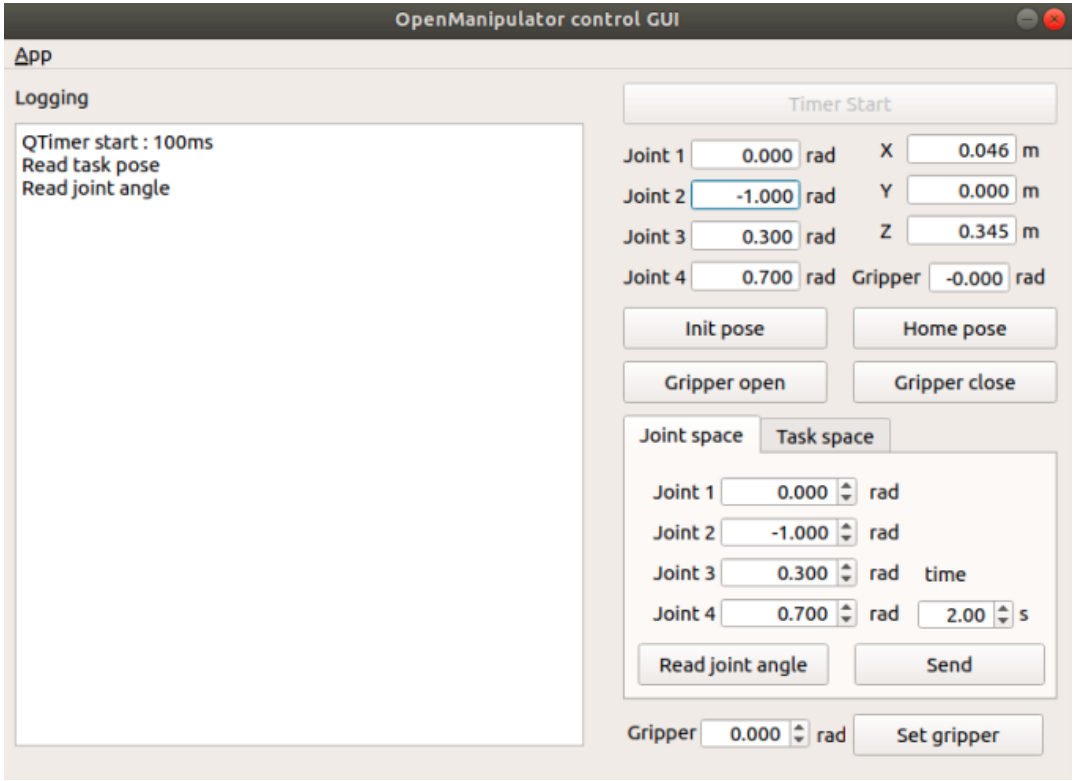
To move the OM while it is fixed on TB3:

1. Run `roscore` and the Bringup node for TB3
2. **On the Remote PC**, **run Bringup node for OM** on TB3:
   - `$ roslaunch turtlebot3_manipulation_bringup turtlebot3_manipulation_bringup.launch`
3. **On the Remote PC**, **run the move_group node**:
   - `$ roslaunch turtlebot3_manipulation_moveit_config move_group.launch`

Manipulation (OM)

Using GUI: In a new terminal, type the command:

```
$ roslaunch turtlebot3_manipulation_gui
turtlebot3_manipulation_gui.launch
```



You can **control the mounted OM using the GUI (left)**:

- **Similar to lessons taught in M3 & M5**
- **Task Space Control** and **Joint Space Control**

Manipulation (OM)

Using rospy: In a new terminal, type the command:

```
$ rosrun autonomous OM_DEMO.py
```

Similar to what was taught in the simulation module (M5), you can **control the mounted OM using python codes**:

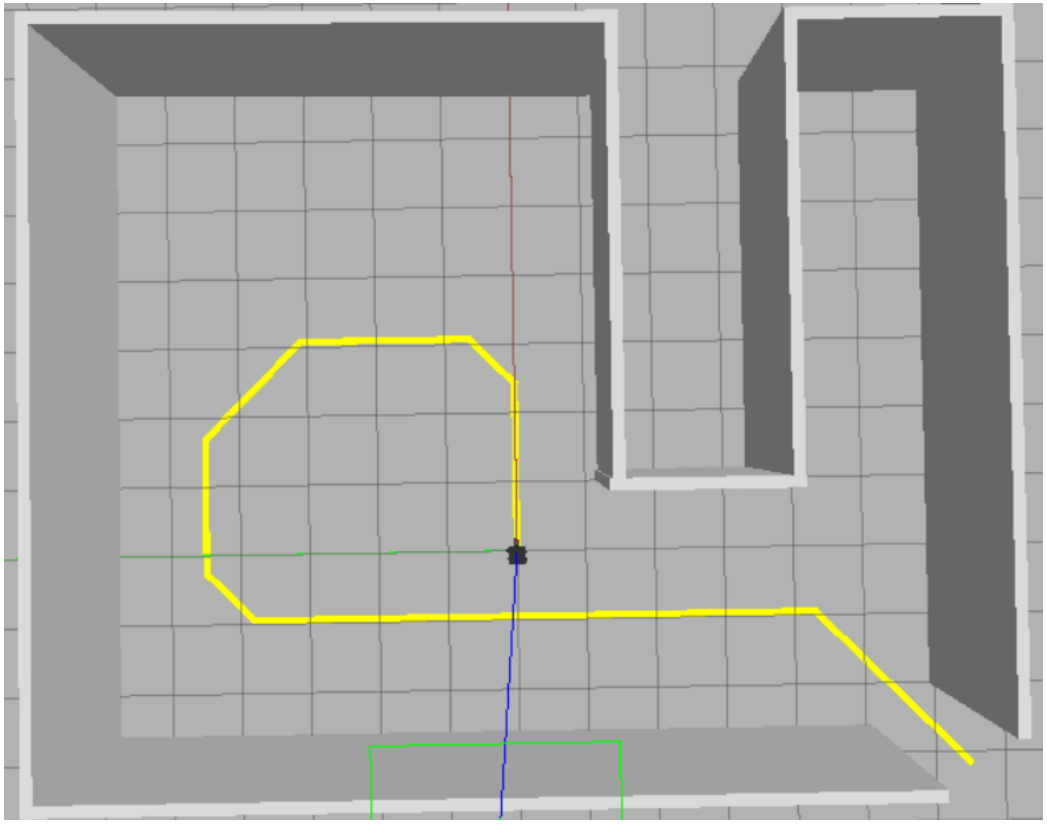
- Change the values for the following variables; under the sub-functions *arm_joints1/2()*

  `joint_goal[X]`

- Change the value for the following variable; under the sub-functions *gripper_open/close()*

  `joint_grip[0]`

Machine Vision



- **TB3 with OM** robot example in Gazebo
- Aim of this exercise is for the robot to **track and follow the yellow line**
- **We are going to do this in real life** (i.e. physical TB3 with physical yellow lines)

Line Follower using MV Example

- Each group will be given **a bright yellow masking tape to mark your lines**
- You **do NOT need the tunnel map** for this exercise
- Find a space, mark your yellow lines using the given tape, and carry out the exercise (explained in next few slides)

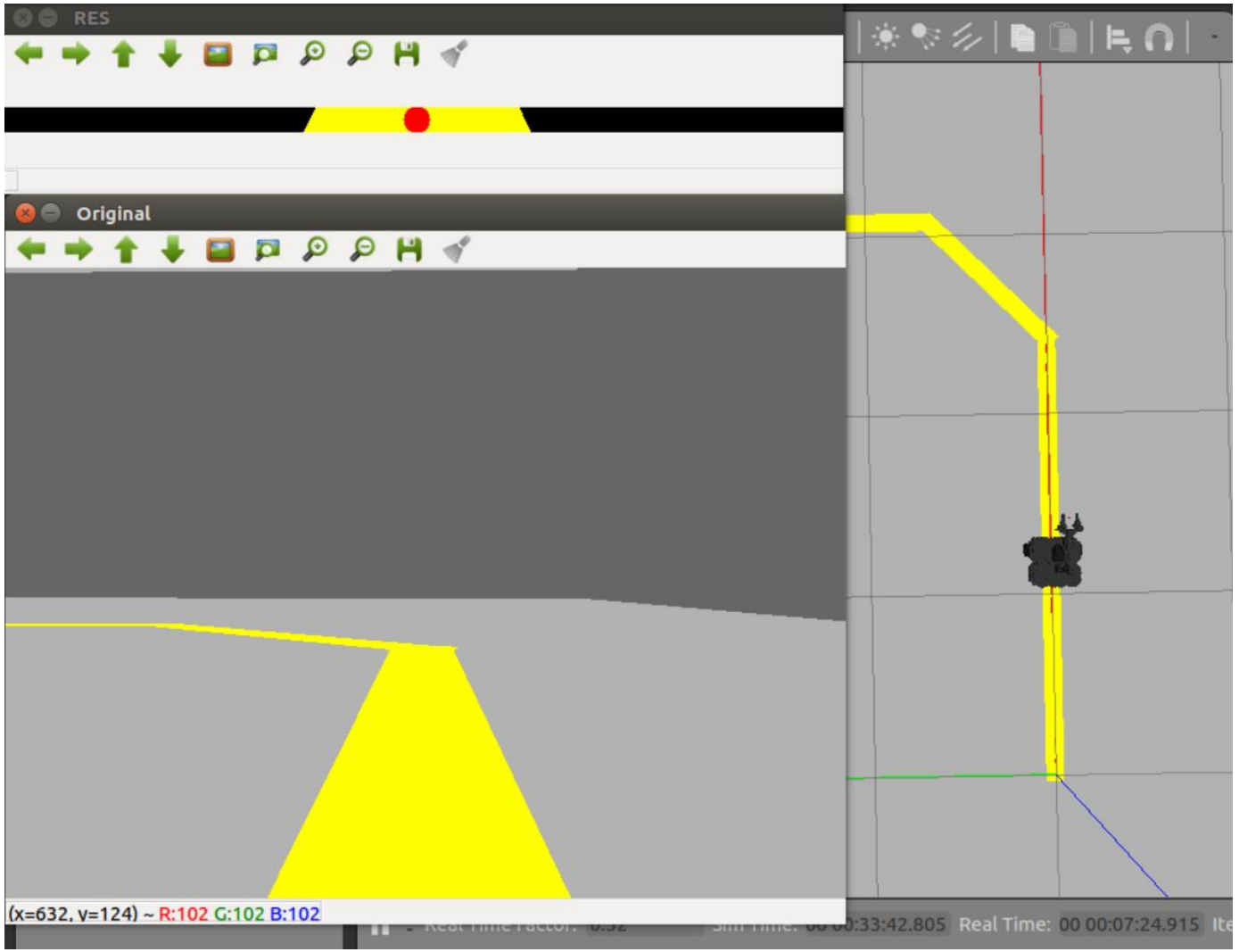
Line Follower using MV Example

Procedures:

1. Place the TB3 at the start of the line with the camera facing the line
2. BringUp the TB3 (with OM) and activate the rpicamera (important step for this exercise!)
3. Compressed image should be transform to raw image (refer to README for command line to do this)
4. Run node example to utilize OpenCV to detect the yellow line and make the TB3 follow it

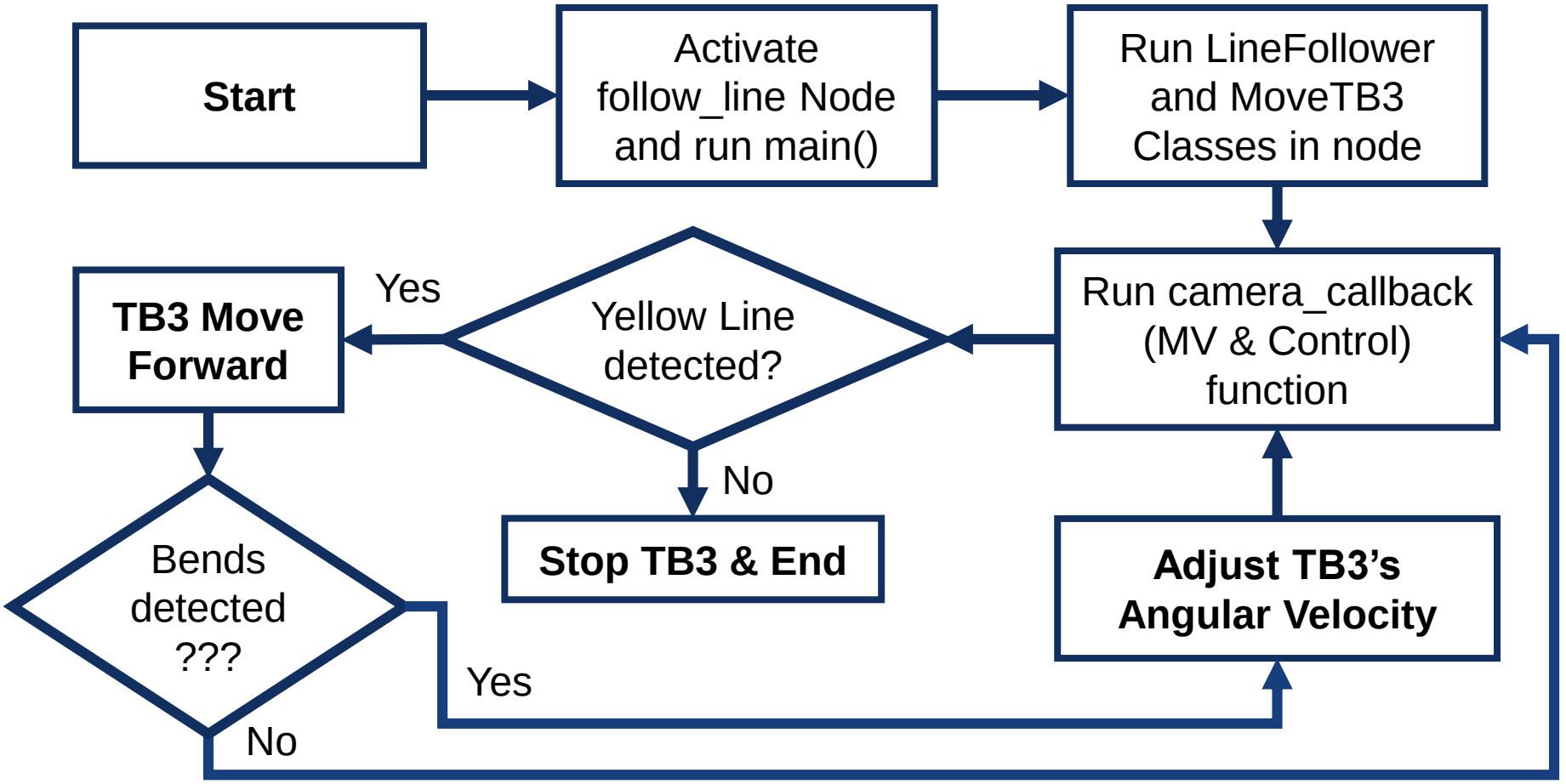
```
$ rosrun autonomous follow_line.py
```

Line Follower using MV Example



Line Follower using MV Example

Block Diagram Representation of Algorithm:



THANK YOU for your kind attention!