GOOD MORNING!
早上好!
안녕하세요!

DAY 3

DAY2 RECAP

DAY 1

- Welcome
- Project Introduction
- Introduction to Project Development Process
- Business Requirement Development
- System Requirement Development
- System and Development environment Setup

DAY 2 (MINI PROJECT)

- Yolo객체 인식 모델 활용과 성능 평가 방법 이해
  - Custom Dataset과 Fine Tuning으로 자체 객체 인식 모델 구현 및 평가
  - (Optional)경량화 모델 등 개별 요구사항에 적합한 모델 탐색 및 성능 검증

DAY 2 (MINI PROJECT)

WEB-CAM 기반 객체 인식 (IF NEEDED)

- YOLOv8 기반 데이터 수집/학습/deploy (Detection Alert)
  - 감시용 데이터 수집(rc_car, dummy, 등)
  - 감시용 데이터 라벨링
  - YOLOv8 기반 학습
  - YOLOv8 Object Detection

AMR-CAM 기반 객체 인식

- AMR(Autonomous Mobile Robot) Turtlebot4 개발 환경 구축
- 로봇 개발 환경에 완성 모델 서빙 및 테스트 / 로봇 H/W, 제반 환경의 한계점 도출
  - Tracking 데이터 수집((rc_car, dummy, 등)
  - Tracking 데이터 라벨링
  - YOLOv8 기반 학습
  - YOLOv8 Object Tracking

DAY 3 (MINI PROJECT)

- Auto. Driving 시스템 학습
  - Digital Mapping of environment
  - Operate AMR (Sim. & Real)
  - Tutorial 실행
  - Detection, Depth and AMR 주행
  - 로봇 개발 환경에 적용 및 테스트 / 로봇 H/W, 제반 환경의 한계점 도출

TURTLEBOT4 시뮬레이션 DEMO

- SLAM과 AutoSLAM으로 맵 생성
- Sim. Tutorial 실행
- Detection, Depth and AMR 주행 example

DAY 3 (MINI PROJECT)

REAL ROBOT

- Manually operating the AMR (Teleops)
- autonomous driving 시스템 with obstacle avoidance
  - Digital Mapping of environment
  - Launching Localization, Nav2, and using Rviz to operate a robot
  - Goal Setting and Obstacle Avoidance using Navigation

TUTORIAL

- Turtlebot4 API를 활용한 Initial Pose Navigate_to Pose 구현
- Turtlebot4 API를 활용한 Navigate_Through_pose, Follow Waypoints 구현

DAY 4 (MINI PROJECT)

- System(High Level) Design (Mini Project)
  - System Architectural Diagram
- Detail Design to Acceptance - Agile Development (SPRINTs)
  - Detection
  - AMR Control

DAY 4 (MINI PROJECT)

CODING, TEST & INTEGRATION

- Coding and Test all modules
- Porting to ROS
- And finally, Integration and Test of Detection Alert & AMR Controller

MINI PROJECT DEMO

- Prepare and demo completed project

프로젝트 RULE NUMBER ONE!!!

Have Fun Fun Fun!

DID YOU ACHIEVE SAME **FOV** AND **DIMENSION** FOR BOTH DEPTH AND RGB??

HOMEWORK CHECK

- **Achieve aligned RGB & Depth FOV**
- Object Detection
  - Collect various datasets (i.e. different topics/images sizes)
  - Create various models (i.e. v5, v8, v11, etc; arg: Epoch, Batch, Imgsz, augmentation, etc)
  - Analyze the results
  - Determine using key metrics which model best fit your solution
  - Using .pt file to predict/inference on pc
  - **Successfully publish the annotated image topic**
- Depth
  - **Find and display the distance to the center of the detected objects**
- Update System Requirement

SYSTEM REQUIREMENT PRESENTATION BY EACH TEAM

Using the posted notes and flipchart as needed

KEY SUBSYSTEM (MODULES) TO DEVELOP

- Detection Alert
  - Camera Capture
  - Object Detection
  - Send messages to other subsystems

- AMR Controller
  - Receive messages and act accordingly
  - Move using (SLAM) with Obstruction avoidance
  - Target Acquisition (Obj. Det.) and Tracking
  - Approach target using camera and motor control

OPERATING AMR

AMR (TURTLEBOT4)

- Features · User Manual
- https://turtlebot.github.io/turtlebot4-user-manual/overview/features.html
- Review the content

SIMULATION DEMO

TUTORIAL(SIM)

- TurtleBot 4 Navigator · User Manual

  https://turtlebot.github.io/turtlebot4-user-manual/tutorials/turtlebot4_navigator.html

SETUP BASH

- Make sure bashrc has:
  - ROS_DOMAIN_ID = Team Number(i.e. 1 or 2 or 3…6)
- Make sure discovery setup.bash is **not** sourced!
- source ~/.bashrc

OPERATING A ROBOT(SIM) – GAZEBO

TERM1

- ros2 launch turtlebot4_ignition_bringup turtlebot4_ignition.launch.py

TERM2

- ros2 topic list
- ros2 topic echo <topic> --once
  - /oakd/rgb/preview/image_raw
  - /oakd/rgb/preview/depth
  - ….

OPERATING A ROBOT(SIM)

- Dock/Undock
- Manual Driving
  - Teleops
- Camera Display
  - RGB/Depth

- Navigation with rviz
  - 2D_Pose_Estimate (initial position)
  - Nav2_Goal

DIGITAL MAPPING USING SLAM (SIM)

TERM1

- ros2 launch turtlebot4_ignition_bringup turtlebot4_ignition.launch.py **nav2:=true slam:=true rviz:=true**

ON GAZEBO

- Undock the robot
- Use keyboard to operate and complete the map

DIGITAL MAPPING WITH AUTO – SLAM (SIM)

TERM1

- ros2 launch turtlebot4_ignition_bringup turtlebot4_ignition.launch.py **nav2:=true slam:=true rviz:=true**
- Undock the robot
- Set init pose from rviz

TERM2

- ros2 launch explore_lite explore.launch.py

TUTORIAL(SIM)

TERMINAL 1

$ ros2 launch turtlebot4_ignition_bringup turtlebot4_ignition.launch.py **nav2:=true slam:=false localization:=true rviz:=true**

- Undock and set init pose

TERMINAL 2

$ ros2 run turtlebot4_python_tutorials nav_to_pose

$ ros2 run turtlebot4_python_tutorials nav_through_poses

$ ros2 run turtlebot4_python_tutorials follow_waypoints

$ ros2 run turtlebot4_python_tutorials create_path

$ ros2 run turtlebot4_python_tutorials mail_delivery

$ ros2 run turtlebot4_python_tutorials patrol_loop

OPERATING REAL ROBOT (AUTONOMOUSLY)

SETUP BASH

- Make sure bashrc has:
  - ROS_DOMAIN_ID = 0
- echo “alias **ros-restart**=‘ros2 daemon stop; ros2 daemon start’" >> ~/.bashrc

- Make sure discovery setup.bash **is** sourced!

- source ~/.bashrc

DIGITAL MAPPING (SLAM)

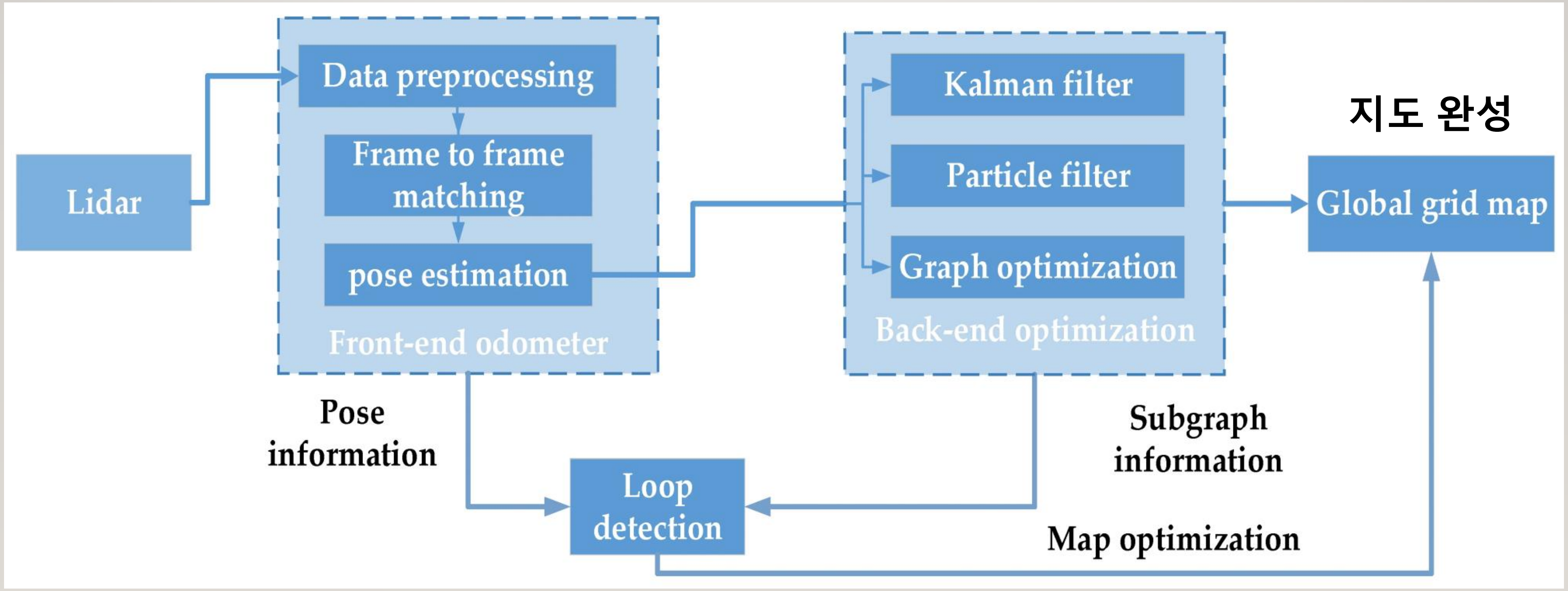
- Generating a map · User Manual
  https://turtlebot.github.io/turtlebot4-user-manual/tutorials/generate_map.html

SLAM 개요

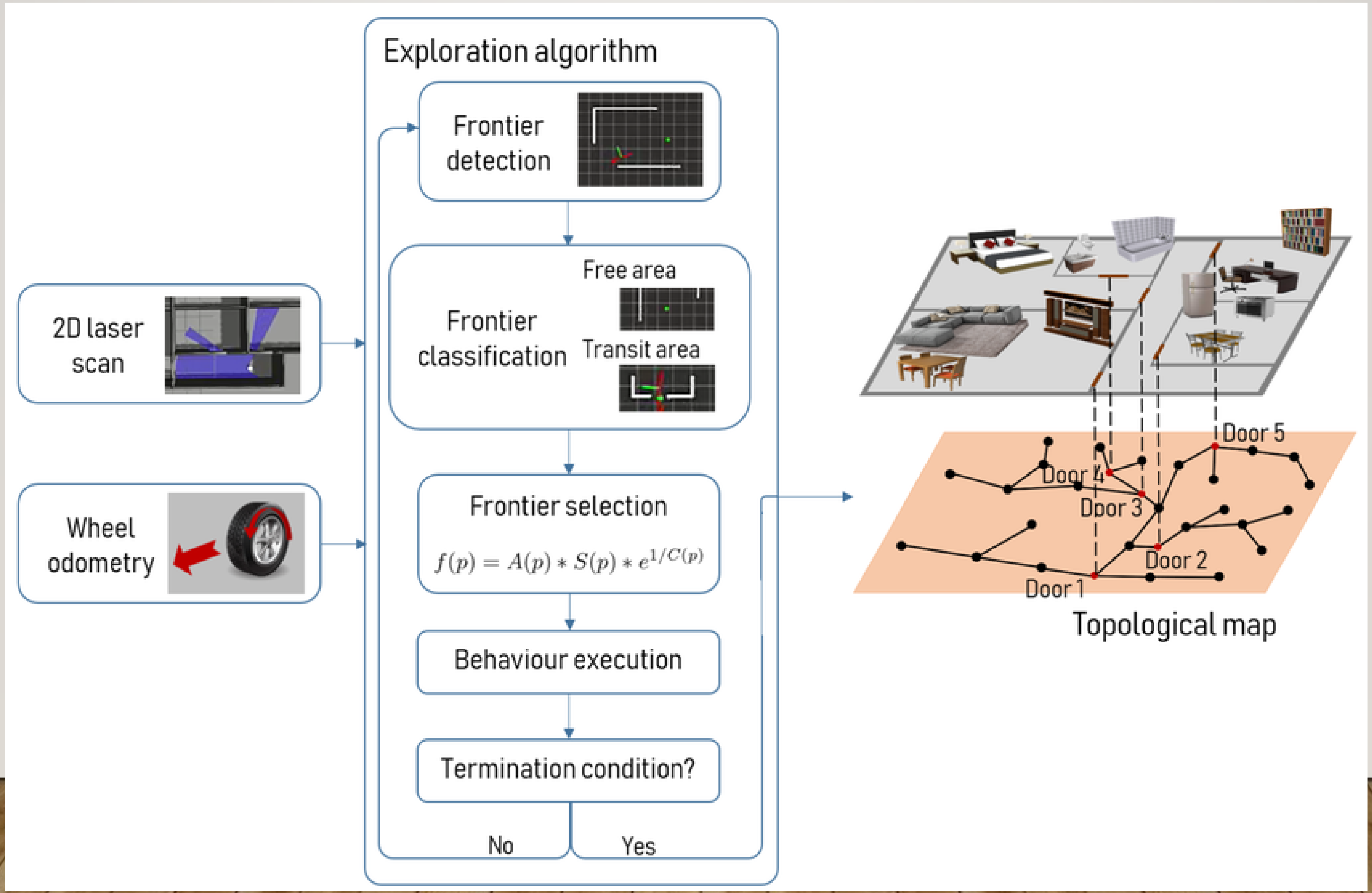
어디 있는지 추정

지나온 길 보정

지도 완성



AUTO SLAM CONCEPT/ALGORITHM



ALGORITHM DETAIL

- Map Subscription

explore_lite subscribes to the SLAM-generated occupancy grid (/map topic) and identifies:

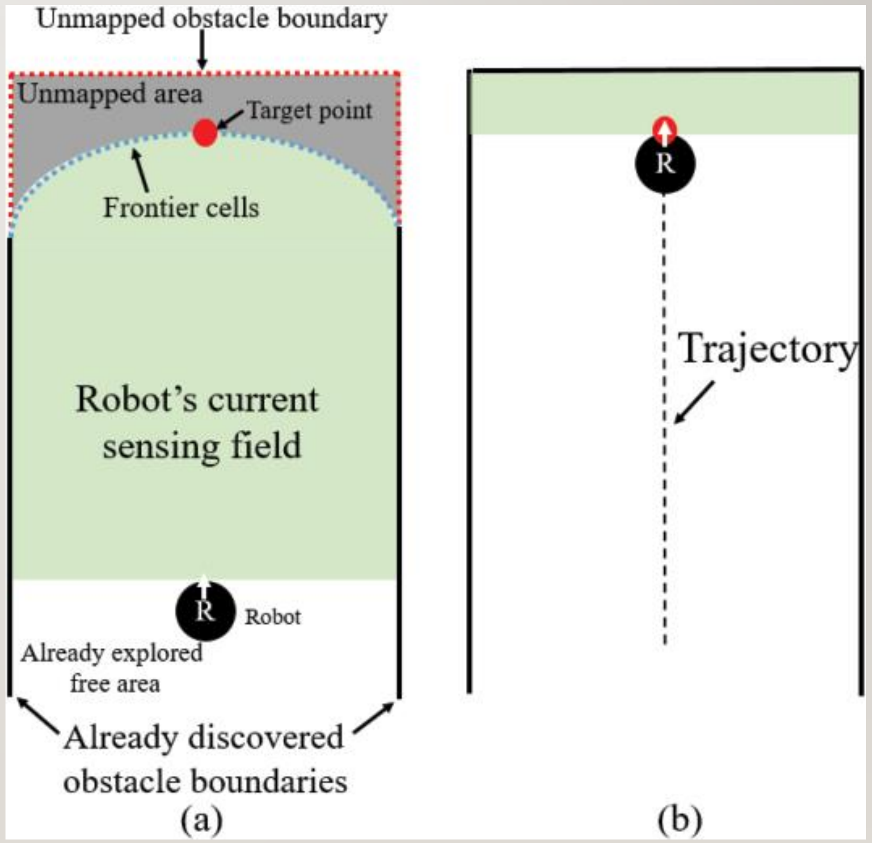
  - Free space: known, unoccupied areas
  - Occupied space: obstacles
  - Unknown space: unexplored

- Frontier Detection

The map is scanned for cells that:

  - Are free, and
  - Are adjacent to at least one unknown cell.

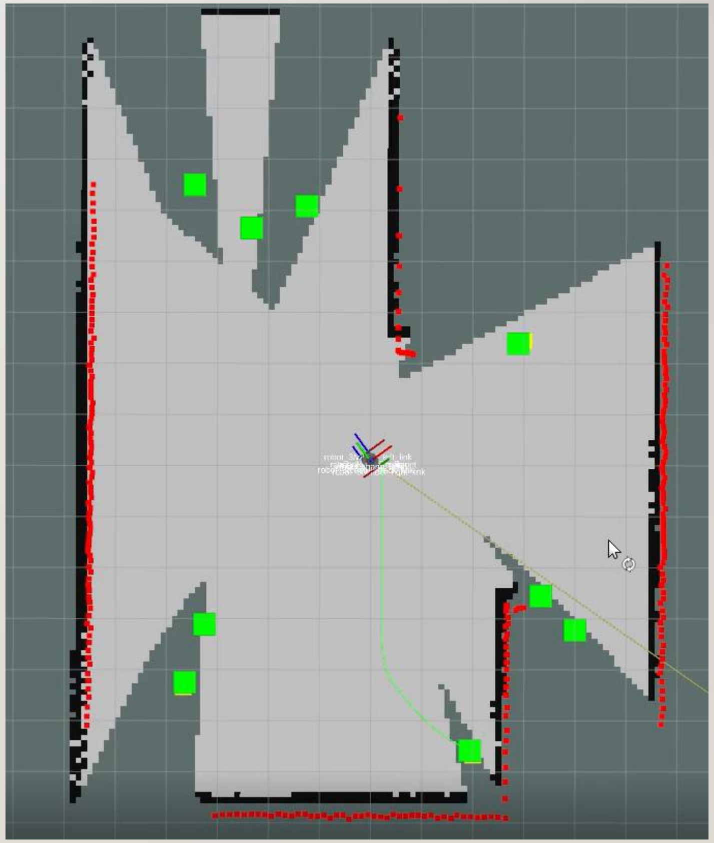
These are marked as frontier cells.


Unmapped obstacle boundary
Unmapped area
Target point
Frontier cells
Robot's current sensing field
R
Robot
Already explored free area
Already discovered obstacle boundaries
(a)
R
Trajectory
(b)

ALGORITHM DETAIL

- Frontier Grouping
  - Frontier cells are clustered into connected regions.
  - Each group represents a potential exploration target.

- Goal Selection
  - For each frontier group, a representative point (typically the centroid or closest point) is selected.
  - The robot scores each group based on:
    - Distance from the robot
    - Information gain (how much new area might be revealed)
  - The best-scoring frontier is chosen as the next goal.

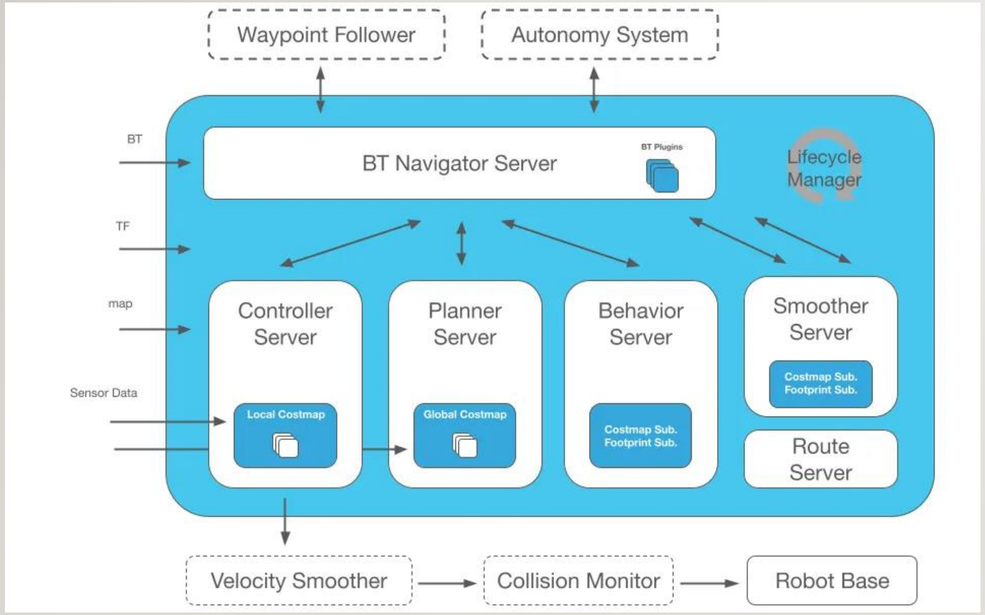


ALGORITHM DETAIL

- Termination

```
While (frontiers exist and reachable)
    Select best frontier
    Send as goal
    If goal fails → blacklist
If (no frontiers or all blacklisted)
    Terminate exploration
```

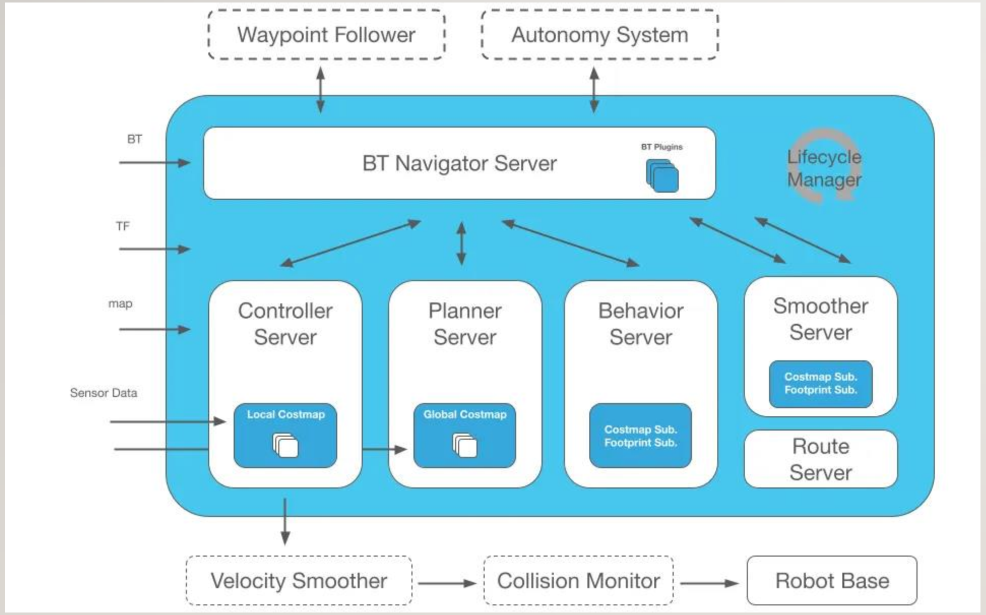
NAV2 IN ONE SENTENCE



- Nav2 turns a goal into safe motion by splitting thinking, reacting, and safety into separate servers.
- One system, many roles
- Behavior Trees coordinate everything
- No single node “drives” the robot

Mental model first. Details later.

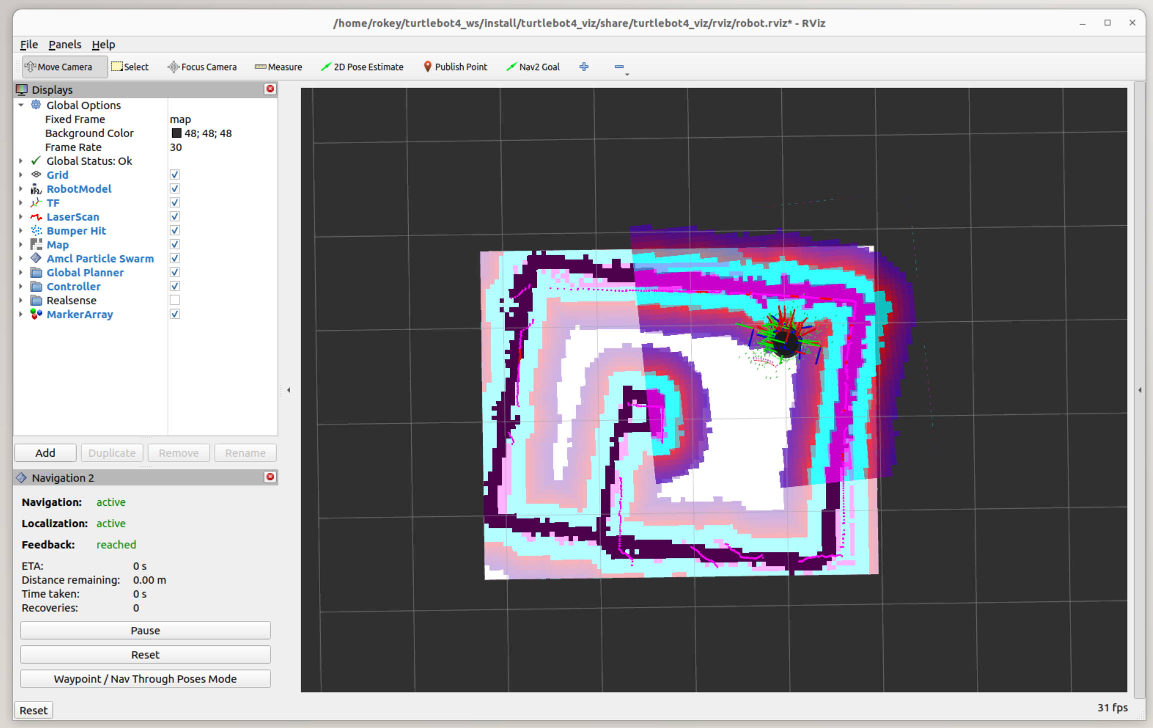
WHO DOES WHAT (CORE SERVERS)



- **BT Navigator**
  Orchestrates the mission using a Behavior Tree
- **Planner Server**
  Computes a global path using the **global costmap**
- **Controller Server**
  Converts the path into velocities using the **local costmap**

Rule: planner thinks far, controller reacts now.

COST MAPS: TWO VIEWS OF THE SAME WORLD



/home/rokey/turtlebot4_ws/install/turtlebot4_viz/share/turtlebot4_viz/rviz/robot.rviz* - RViz

Displays

Global Options	
Fixed Frame	map
Background Color	■ 48; 48; 48
Frame Rate	30
✓ Global Status: Ok	
Grid	✓
RobotModel	✓
TF	✓
LaserScan	✓
Bumper Hit	✓
Map	✓
Amcl Particle Swarm	✓
Global Planner	✓
Controller	✓
Realsense	☐
MarkerArray	✓

Navigation 2

Navigation: active
Localization: active
Feedback: reached

ETA:	0 s
Distance remaining:	0.00 m
Time taken:	0 s
Recoveries:	0

31 fps

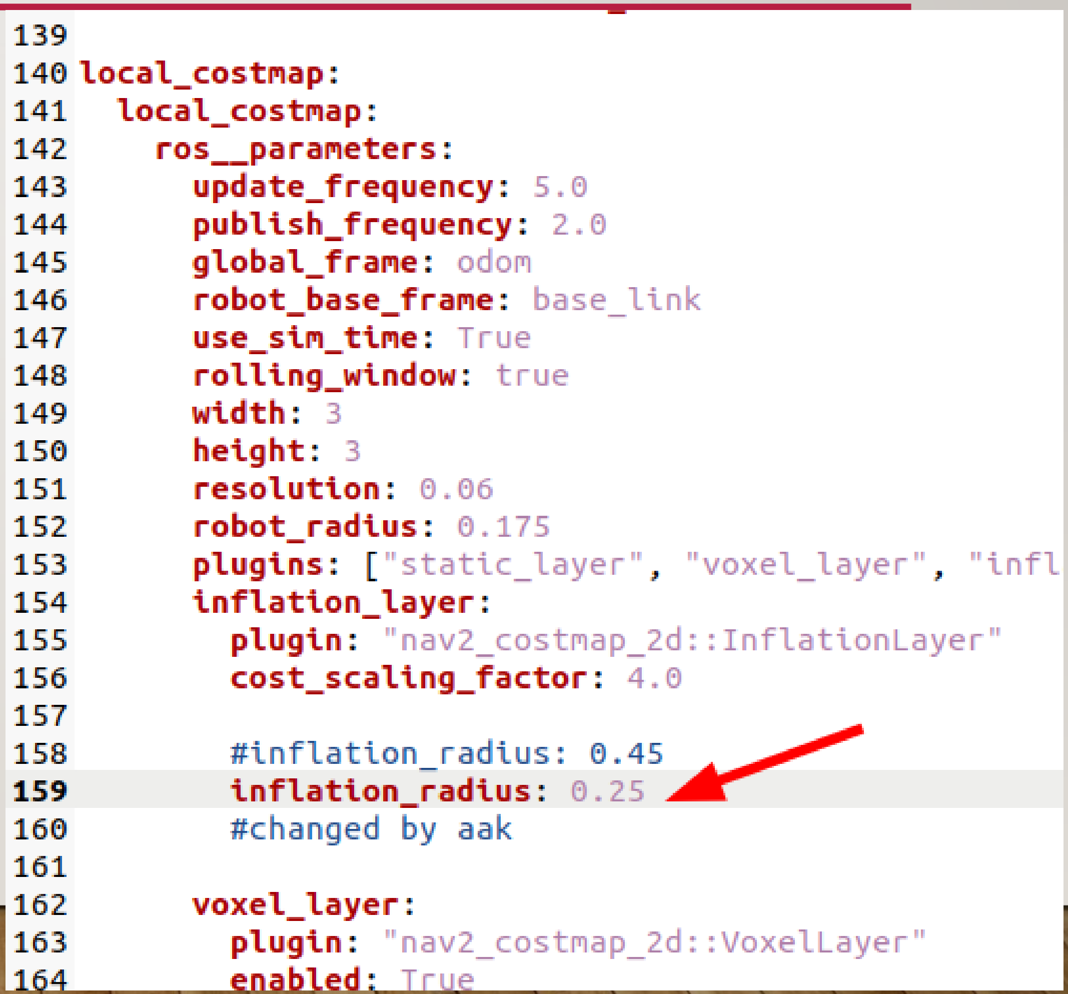
- **Global Costmap**
  - Static, slow, conservative
  - Used for planning
- **Local Costmap**
  - Dynamic, fast, sensor-driven
  - Used for control

Same environment. Different time horizons.

SIMPLE NAV2 PARAM ADJUSTMENT

$ cd ~/turtlebot4_ws/src/turtlebot4/turtlebot4_navigation/config

- Change/adjust "inflation_radius" to fit your environment

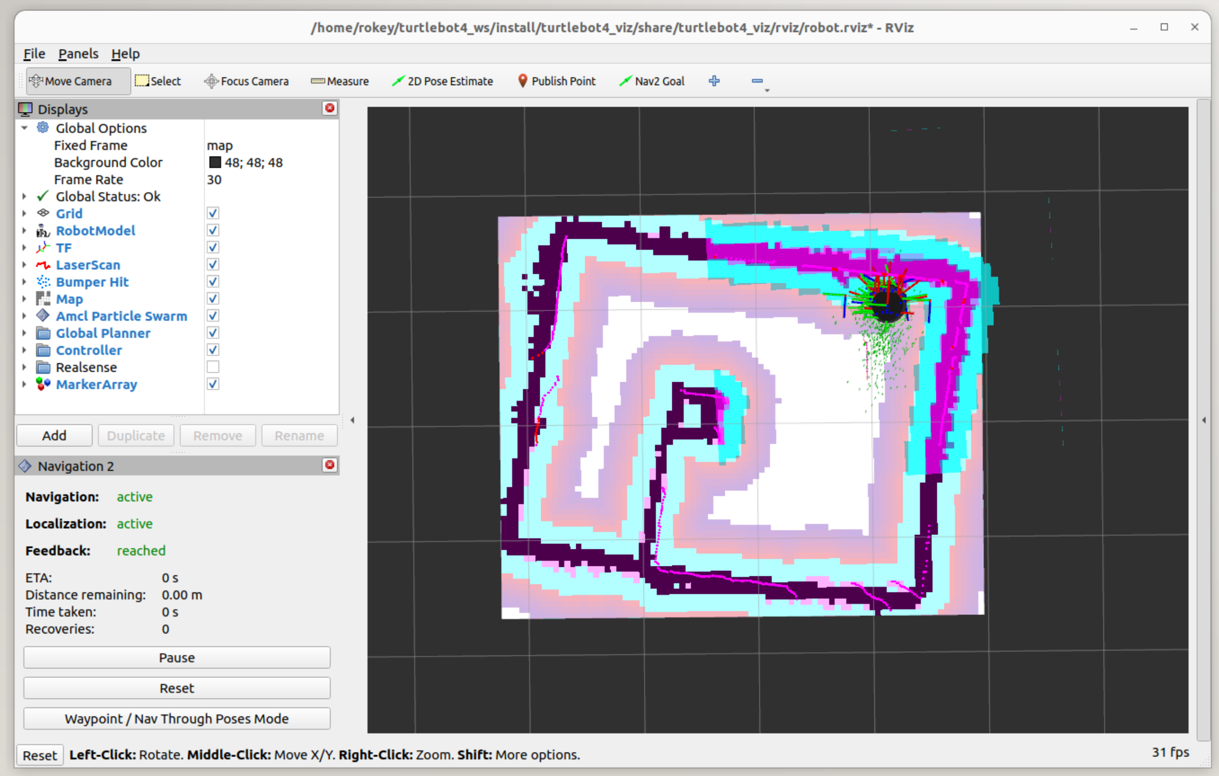


```
local_costmap:
  local_costmap:
    ros__parameters:
      update_frequency: 5.0
      publish_frequency: 2.0
      global_frame: odom
      robot_base_frame: base_link
      use_sim_time: True
      rolling_window: true
      width: 3
      height: 3
      resolution: 0.06
      robot_radius: 0.175
      plugins: ["static_layer", "voxel_layer", "infl
      inflation_layer:
        plugin: "nav2_costmap_2d::InflationLayer"
        cost_scaling_factor: 4.0

        #inflation_radius: 0.45
        inflation_radius: 0.25
        #changed by aak

      voxel_layer:
        plugin: "nav2_costmap_2d::VoxelLayer"
        enabled: True
```

COST MAPS WITH PARAMETER ADJUSTMENTS



Displays

Global Options	
Fixed Frame	map
Background Color	■ 48; 48; 48
Frame Rate	30
✓ Global Status: Ok	
Grid	✓
RobotModel	✓
TF	✓
LaserScan	✓
Bumper Hit	✓
Map	✓
Amcl Particle Swarm	✓
Global Planner	✓
Controller	✓
Realsense	☐
MarkerArray	✓

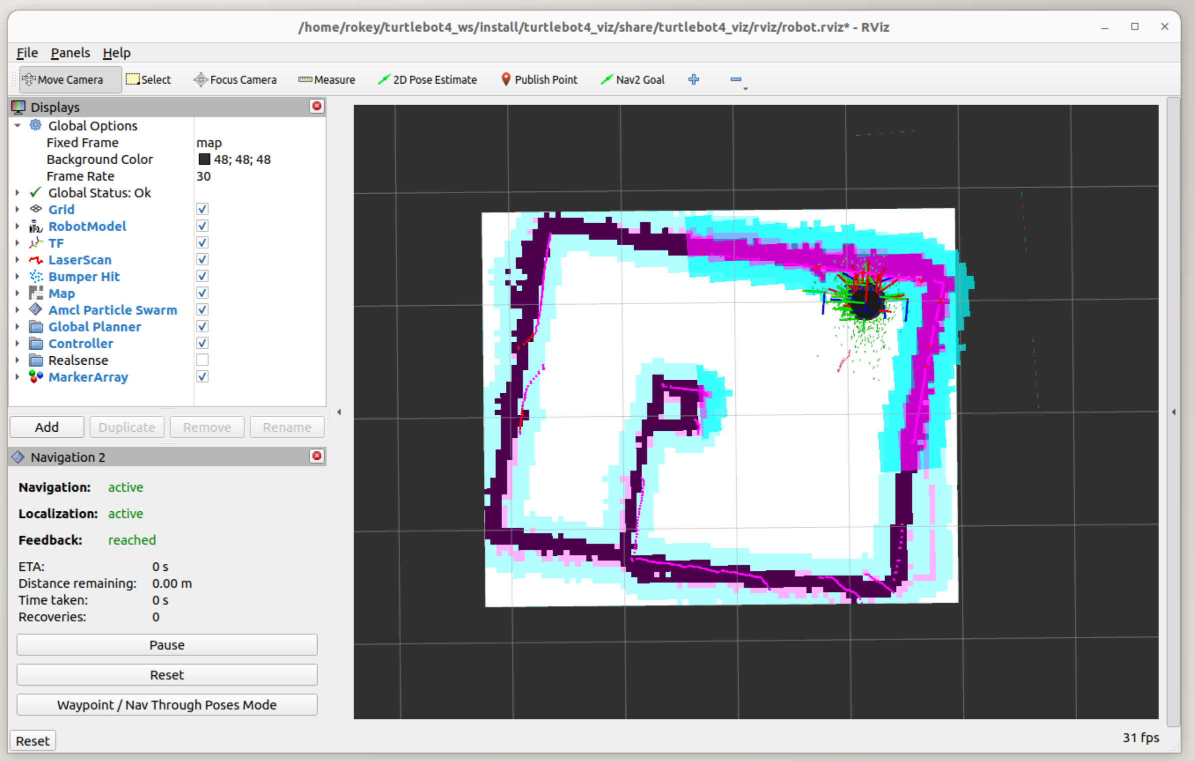
Navigation 2

Navigation: active
Localization: active
Feedback: reached

ETA: 0 s
Distance remaining: 0.00 m
Time taken: 0 s
Recoveries: 0

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click:** Zoom. **Shift:** More options.

31 fps



Displays

Global Options	
Fixed Frame	map
Background Color	■ 48; 48; 48
Frame Rate	30
✓ Global Status: Ok	
Grid	✓
RobotModel	✓
TF	✓
LaserScan	✓
Bumper Hit	✓
Map	✓
Amcl Particle Swarm	✓
Global Planner	✓
Controller	✓
Realsense	☐
MarkerArray	✓

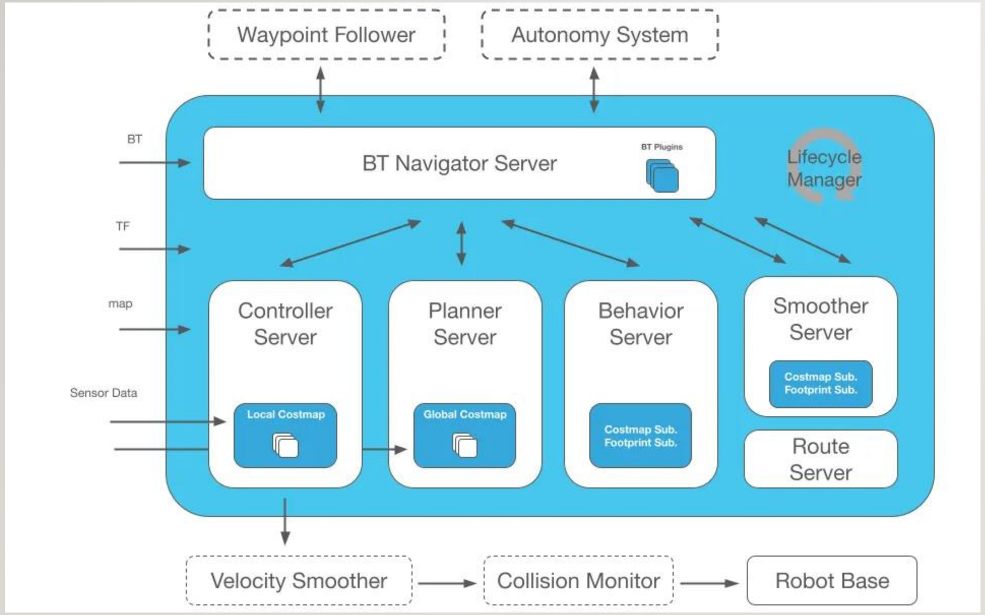
Navigation 2

Navigation: active
Localization: active
Feedback: reached

ETA: 0 s
Distance remaining: 0.00 m
Time taken: 0 s
Recoveries: 0

31 fps

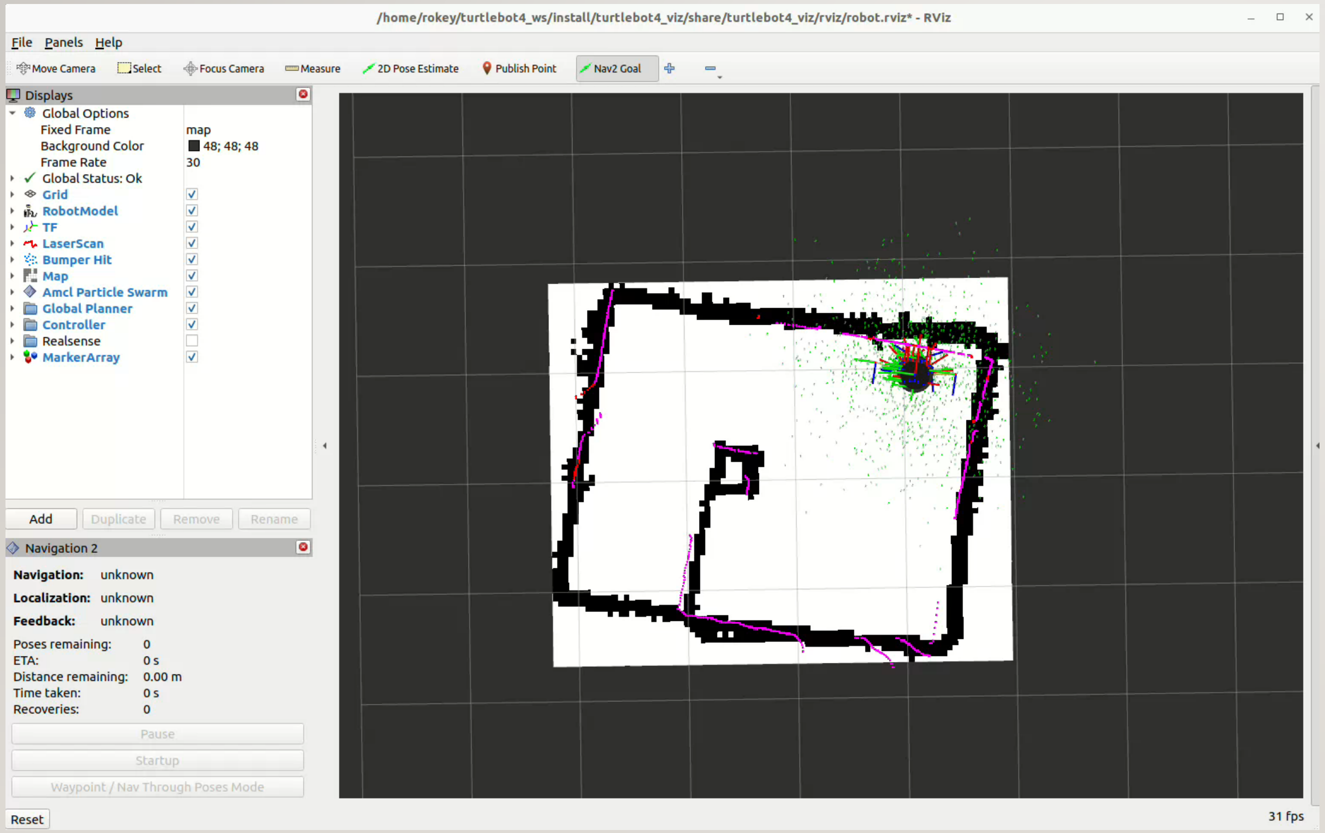
HANDLING REALITY (RECOVERY + SAFETY)



- **Behavior Server**
  - Spin, back up, wait, clear costmaps
  - Triggered when progress fails
- **Safety Chain**
  - Velocity smoother
  - Collision monitor
  - Robot base veto power

Intelligence suggests. Safety decides.

END-TO-END FLOW



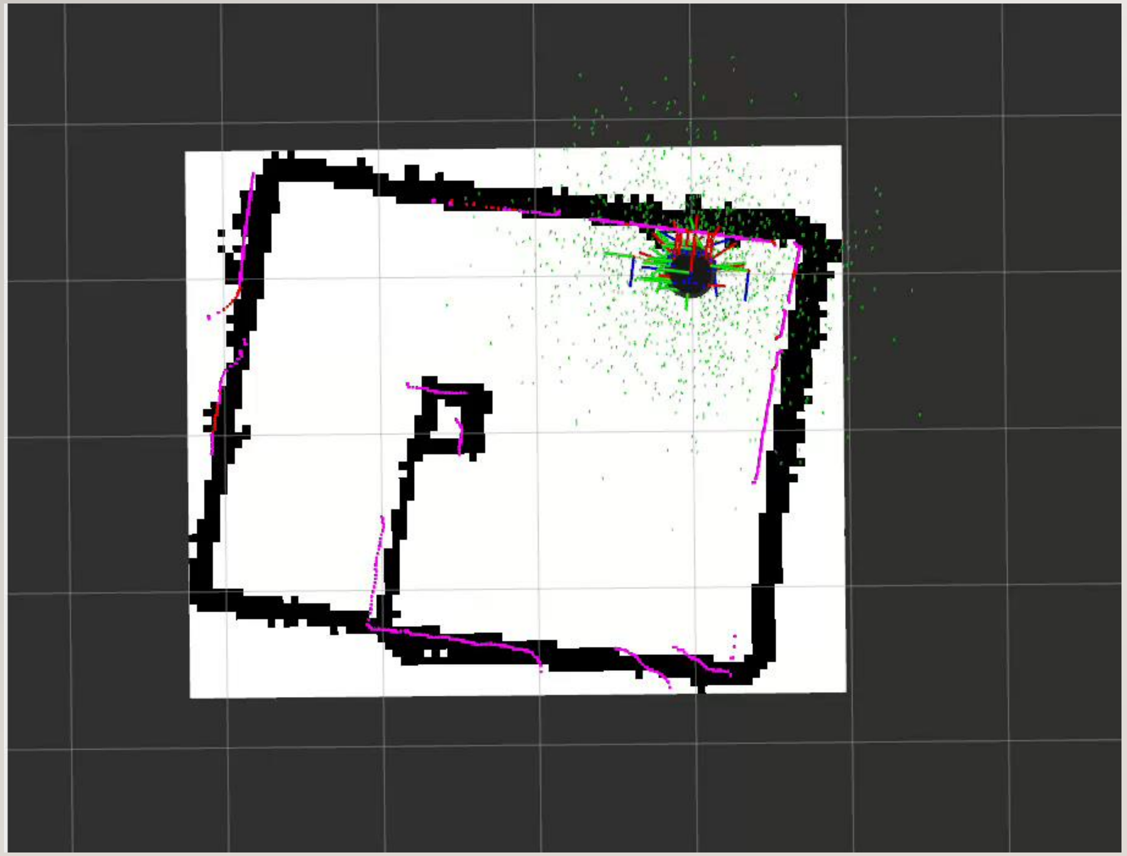
Global Options
Fixed Frame: map
Background Color: 48; 48; 48
Frame Rate: 30
Global Status: Ok

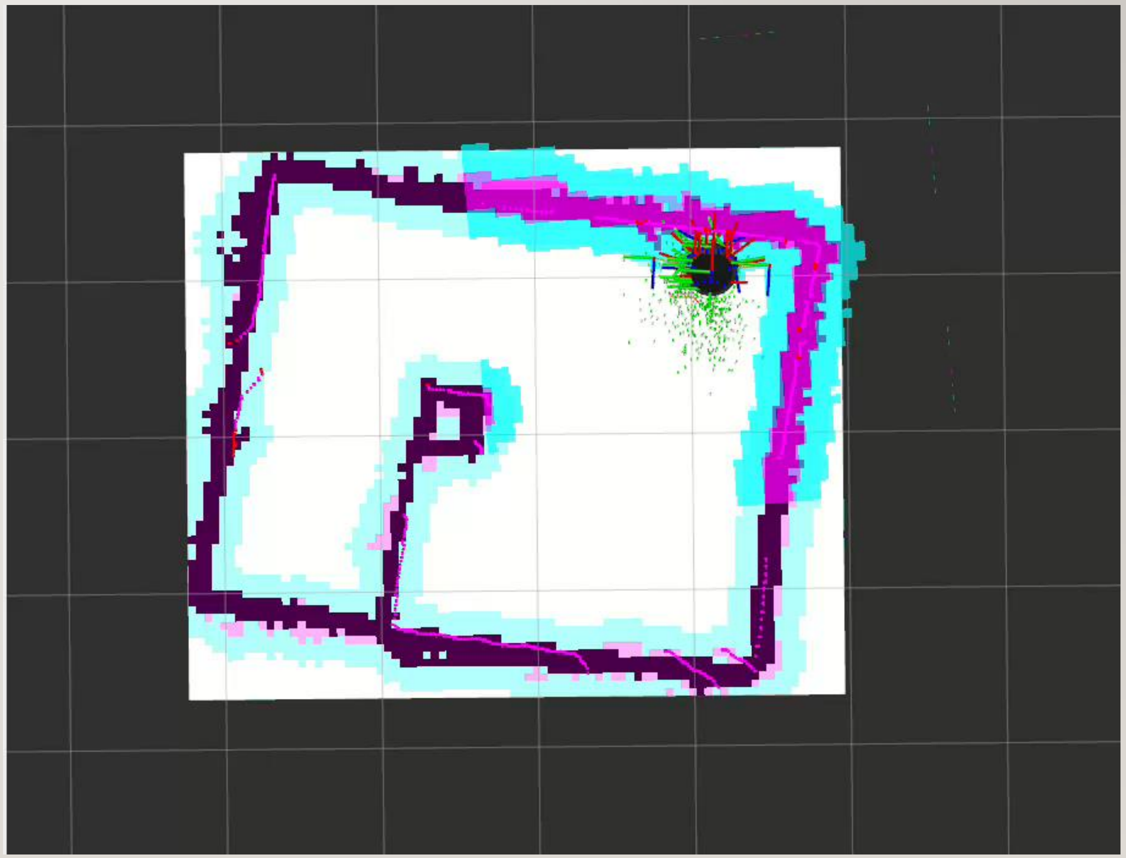
Navigation: unknown
Localization: unknown
Feedback: unknown
Poses remaining: 0
ETA: 0 s
Distance remaining: 0.00 m
Time taken: 0 s
Recoveries: 0

1. Goal arrives
2. BT selects actions
3. Planner creates path
4. Controller drives
5. Safety filters motion
6. Behavior recovers if needed

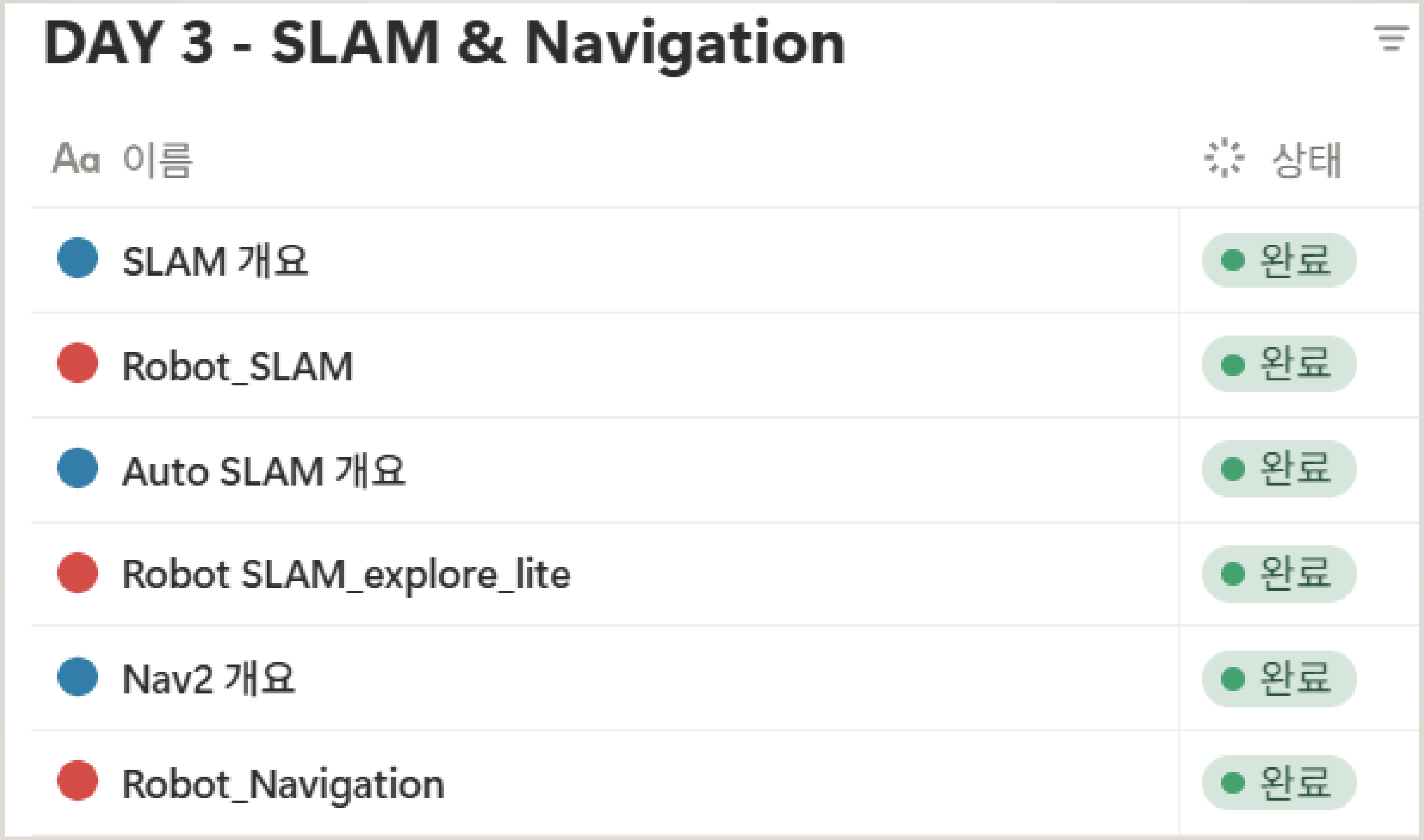
Loop until success or failure.

END-TO-END FLOW WITH PARAMETER ADJUSTMENT





EXERCISE: PERFORM SLAM TO NAVIGATION



DAY 3 - SLAM & Navigation

Aa 이름	상태
🔵 SLAM 개요	● 완료
🔴 Robot_SLAM	● 완료
🔵 Auto SLAM 개요	● 완료
🔴 Robot SLAM_explore_lite	● 완료
🔵 Nav2 개요	● 완료
🔴 Robot_Navigation	● 완료

EXERCISE : RUN TUTORIAL ON REAL ROBOT

Make copy and Update the ***simulation*** tutorial code provided to successfully execute in the project environment with ***real robot***

Tutorial Codes are found in:
$HOME/turtlebot4_ws/src/turtlebot4_tutorials/turtlebot4_python_tutorials/turtlebot4_python_tutorials

SETUP BASH(ROBOT)

- Make sure bashrc has:
  - ROS_DOMAIN_ID = Team Number(i.e. 1 or 2 or 3…6)

- Make sure discovery setup.bash **is** sourced!

- source ~/.bashrc

TUTORIAL

TERMINAL 1

```
$ ros2 launch turtlebot4_navigation localization.launch.py namespace:=/robot<n> map:=$HOME/Documents/room/room_map.yaml
```

TERMINAL 2

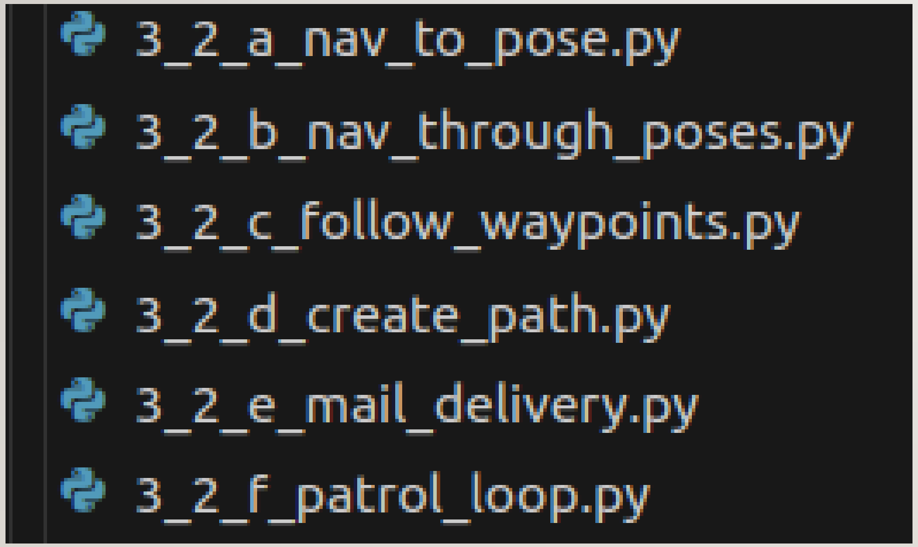
```
$ ros2 launch turtlebot4_viz view_robot.launch.py namespace:=/robot <n>
```

- Set Init Pose using 2D_PoseEstimate
- Undock Robot

TERMINAL 3

```
$ ros2 launch turtlebot4_navigation nav2.launch.py namespace:=/robot <n>
```

TUTORIAL (ROBOT) EXAMPLE CLI



```
3_2_a_nav_to_pose.py
3_2_b_nav_through_poses.py
3_2_c_follow_waypoints.py
3_2_d_create_path.py
3_2_e_mail_delivery.py
3_2_f_patrol_loop.py
```

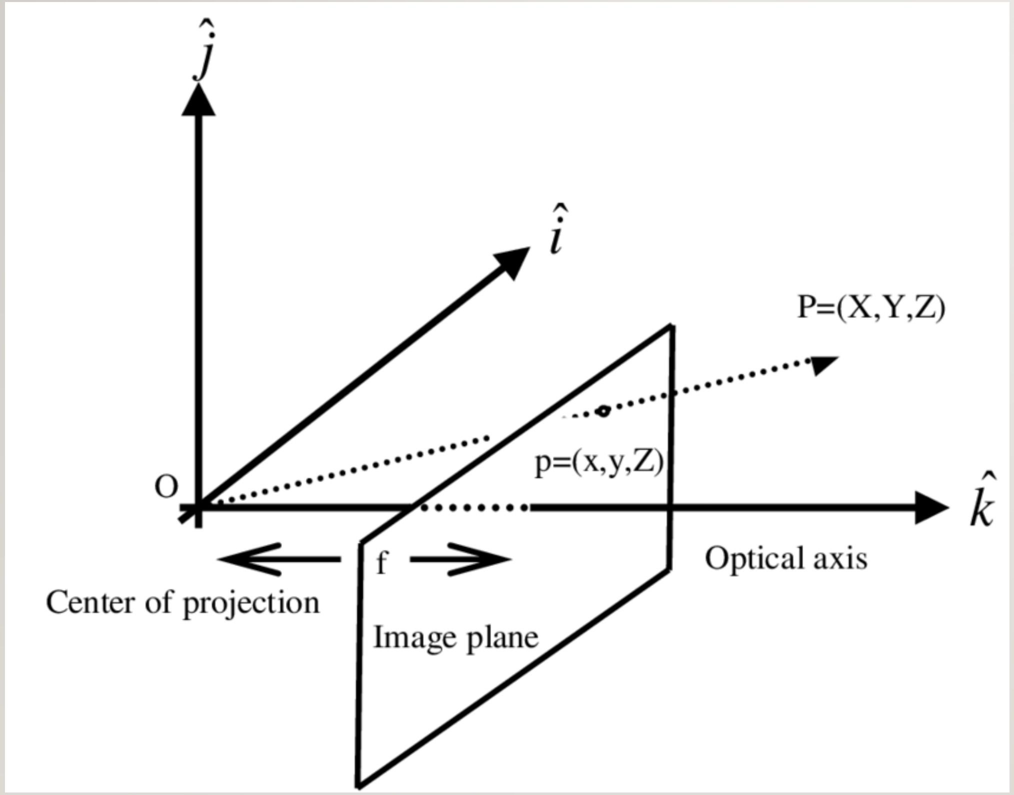
TERMINAL 4

```
$ ros2 run day3 create_path --ros-args -r __ns:=/robot<n>
$ ros2 run day3 nav_to_poses --ros-args -r __ns:=/robot<n>
$ ros2 run day3 follow_waypoints --ros-args -r
  __ns:=/robot<n>
$ ros2 run day3 nav_through_poses --ros-args -r
  __ns:=/robot<n>
$ ros2 run day3 mail_delivery --ros-args -r __ns:=/robot<n>
$ ros2 run day3 patrol_loop --ros-args -r __ns:=/robot<n>
```

HINT: Just need to find new coordinates for the goal(s)

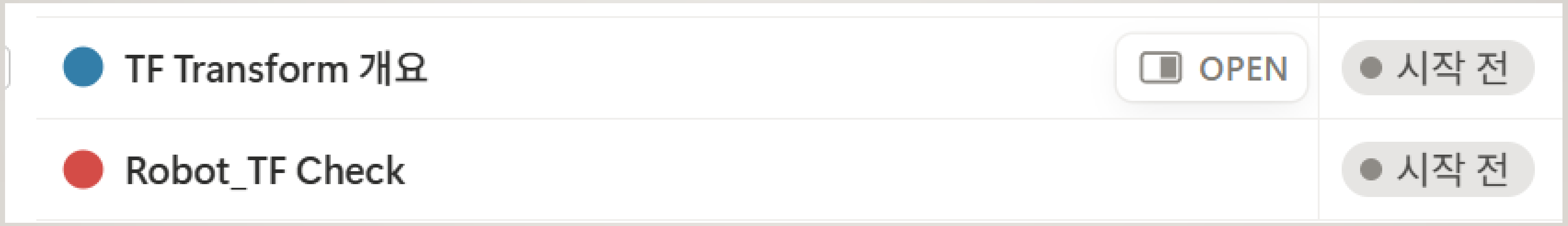
USING DEPTH TO GET MAP COORDINATES (TF TRANSFORM)

CAMERA INTRINSIC AND REPROJECTION



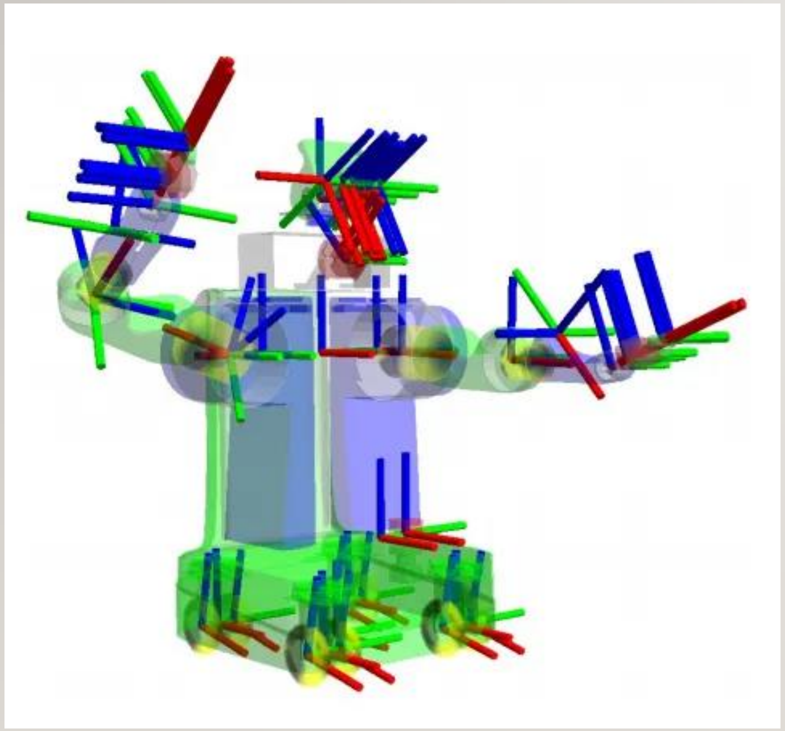
$$X = \frac{(u - c_x) \cdot Z}{f_x}, \quad Y = \frac{(v - c_y) \cdot Z}{f_y}, \quad Z = Z$$

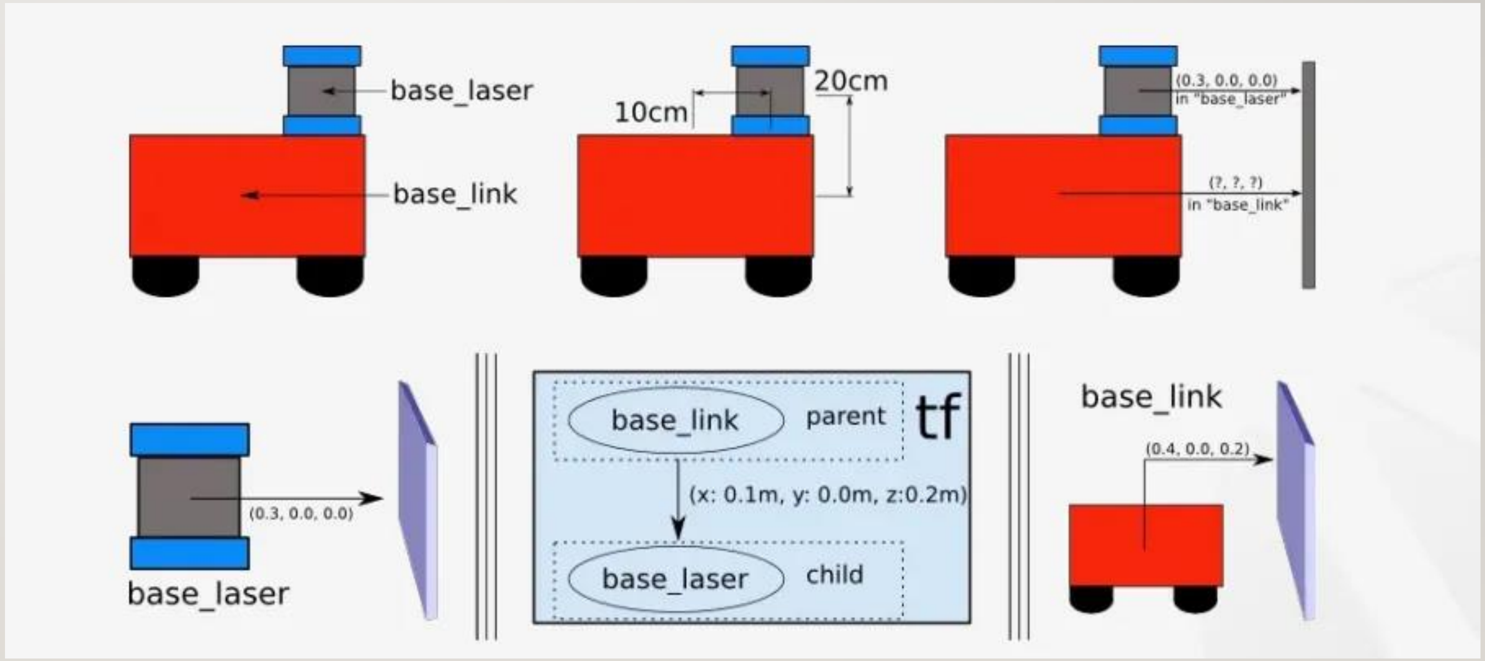
TF TRANSFORM 개요



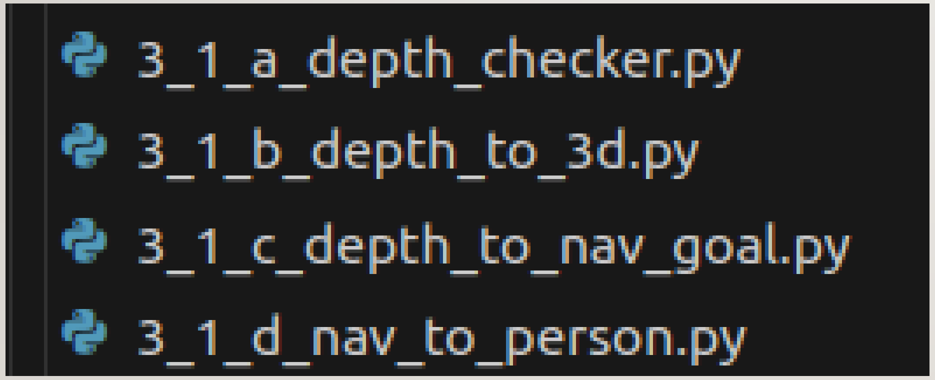
🔵 TF Transform 개요	OPEN	● 시작 전
🔴 Robot_TF Check		● 시작 전

TF (ROBOT TRANSFORM) 개요





USING DEPTH (SIM)



```
3_1_a_depth_checker.py
3_1_b_depth_to_3d.py
3_1_c_depth_to_nav_goal.py
3_1_d_nav_to_person.py
```

TERMINAL 2 (

```
$ ros2 run <pkg_name> <exec_name>
```

For example,

```
$ ros2 run day3 nav_to_person
```

DEPTH/TRANSFORM EXERCISE

Make copy and Update the ***simulation*** depth code provided to successfully execute in the project environment with ***real robot***

Simulation Depth Codes are found on **Github**

USING DEPTH (ROBOT)

TERMINAL 1

```
$ ros2 launch turtlebot4_navigation localization.launch.py namespace:=/robot<n> map:=$HOME/Documents/room/room_map.yaml
```

TERMINAL 2

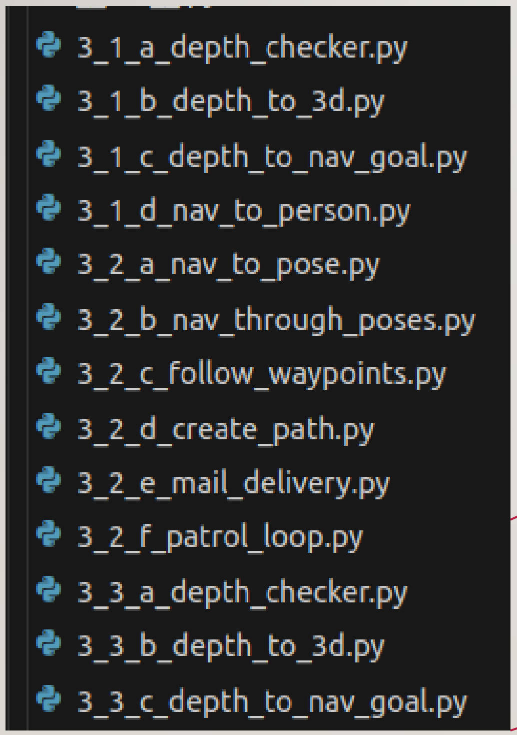
```
$ ros2 launch turtlebot4_viz view_robot.launch.py namespace:=/robot <n>
```

- Set Init Pose using 2D_PoseEstimate
- Undock Robot

TERMINAL 3

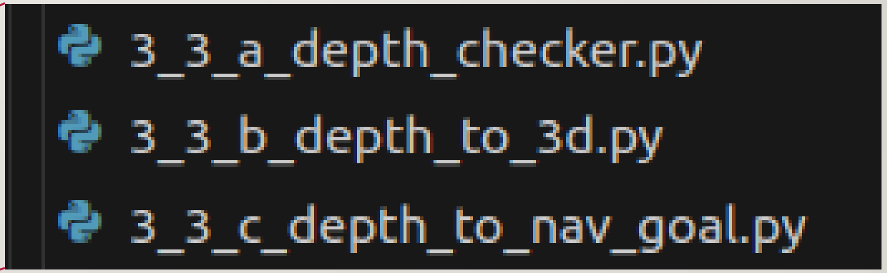
```
$ ros2 launch turtlebot4_navigation nav2.launch.py namespace:=/robot <n>
```

USING DEPTH (ROBOT)



```
3_1_a_depth_checker.py
3_1_b_depth_to_3d.py
3_1_c_depth_to_nav_goal.py
3_1_d_nav_to_person.py
3_2_a_nav_to_pose.py
3_2_b_nav_through_poses.py
3_2_c_follow_waypoints.py
3_2_d_create_path.py
3_2_e_mail_delivery.py
3_2_f_patrol_loop.py
3_3_a_depth_checker.py
3_3_b_depth_to_3d.py
3_3_c_depth_to_nav_goal.py
```

Simulation Code

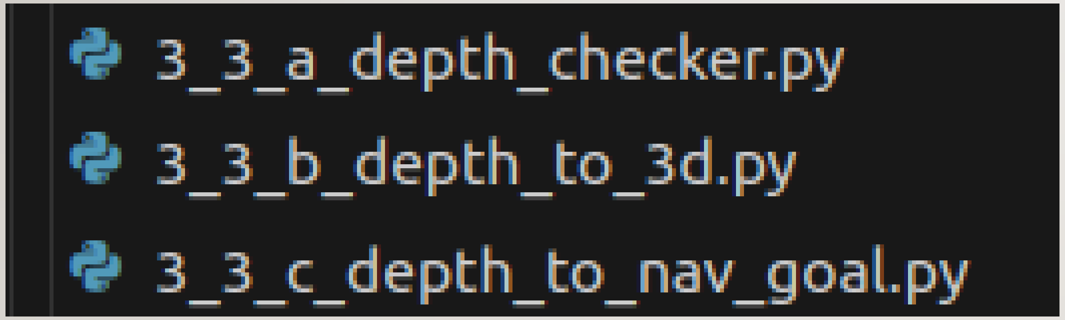


```
3_3_a_depth_checker.py
3_3_b_depth_to_3d.py
3_3_c_depth_to_nav_goal.py
```

Provided Code

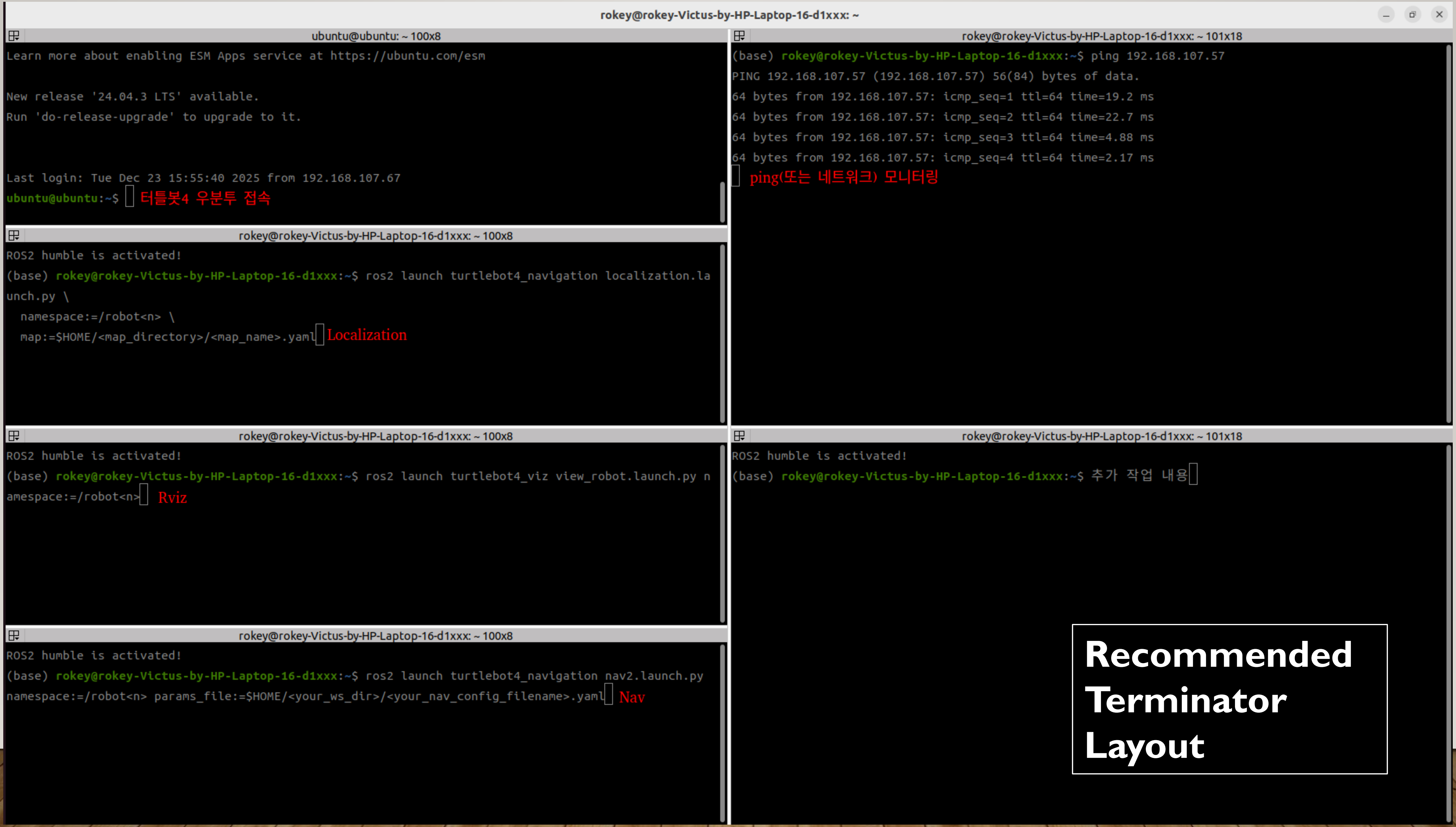
Provided code can be found on Github

USING DEPTH/TRANSFORM (ROBOT) EXAMPLE CLI



```
3_3_a_depth_checker.py
3_3_b_depth_to_3d.py
3_3_c_depth_to_nav_goal.py
```

- $ ros2 run day4 depth_checker **--ros-args -r __ns:=/robot<n>**
- $ ros2 run day4 depth_to_3d **--ros-args -r __ns:=/robot<n> -r /tf:=/robot<n>/tf –r /tf_static:=/robot<n>/tf_static**
- $ ros2 run day4 depth_to_goal **--ros-args -r __ns:=/robot<n> -r /tf:=/robot<n>/tf –r /tf_static:=/robot<n>/tf_static**



rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~

ubuntu@ubuntu: ~ 100x8

```
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: Tue Dec 23 15:55:40 2025 from 192.168.107.67
ubuntu@ubuntu:~$
```

터틀봇4 우분투 접속

rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~ 100x8

```
ROS2 humble is activated!
(base) rokey@rokey-Victus-by-HP-Laptop-16-d1xxx:~$ ros2 launch turtlebot4_navigation localization.la
unch.py \
  namespace:=/robot<n> \
  map:=$HOME/<map_directory>/<map_name>.yaml
```

Localization

rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~ 100x8

```
ROS2 humble is activated!
(base) rokey@rokey-Victus-by-HP-Laptop-16-d1xxx:~$ ros2 launch turtlebot4_viz view_robot.launch.py n
amespace:=/robot<n>
```

Rviz

rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~ 100x8

```
ROS2 humble is activated!
(base) rokey@rokey-Victus-by-HP-Laptop-16-d1xxx:~$ ros2 launch turtlebot4_navigation nav2.launch.py
namespace:=/robot<n> params_file:=$HOME/<your_ws_dir>/<your_nav_config_filename>.yaml
```

Nav

rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~ 101x18

```
(base) rokey@rokey-Victus-by-HP-Laptop-16-d1xxx:~$ ping 192.168.107.57
PING 192.168.107.57 (192.168.107.57) 56(84) bytes of data.
64 bytes from 192.168.107.57: icmp_seq=1 ttl=64 time=19.2 ms
64 bytes from 192.168.107.57: icmp_seq=2 ttl=64 time=22.7 ms
64 bytes from 192.168.107.57: icmp_seq=3 ttl=64 time=4.88 ms
64 bytes from 192.168.107.57: icmp_seq=4 ttl=64 time=2.17 ms
```

ping(또는 네트워크) 모니터링

rokey@rokey-Victus-by-HP-Laptop-16-d1xxx: ~ 101x18

```
ROS2 humble is activated!
(base) rokey@rokey-Victus-by-HP-Laptop-16-d1xxx:~$ 추가 작업 내용
```

Recommended Terminator Layout

HOMEWORK

- Create an AMR control code
  - AMR receives an event and undocks
  - Init Pose is set
  - AMR moves to a goal position
  - AMR able to approach a target
    - **Design a way to get information about the target**
    - **Design an approach algorithm**
    - **Test**
- Update System Requirement

프로젝트 RULE NUMBER ONE!!!

Are we still having FUN!

MERRY CHRISTMAS EVERYONE!!