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Introduction

Internet of Things (IoT)

- Internet of Things (IoT) devices exchange data with other devices across the Internet or other communication networks.
- Enables monitoring, control and automation of physical systems.

Internet of Robotic Things (IoRT)

- Extension of IoT where robots become active nodes.
- Robots not only sense and communicate, but also act and adapt to the environment.

Introduction

Problem

Commercial cleaning robots (e.g. Roomba) are limited:

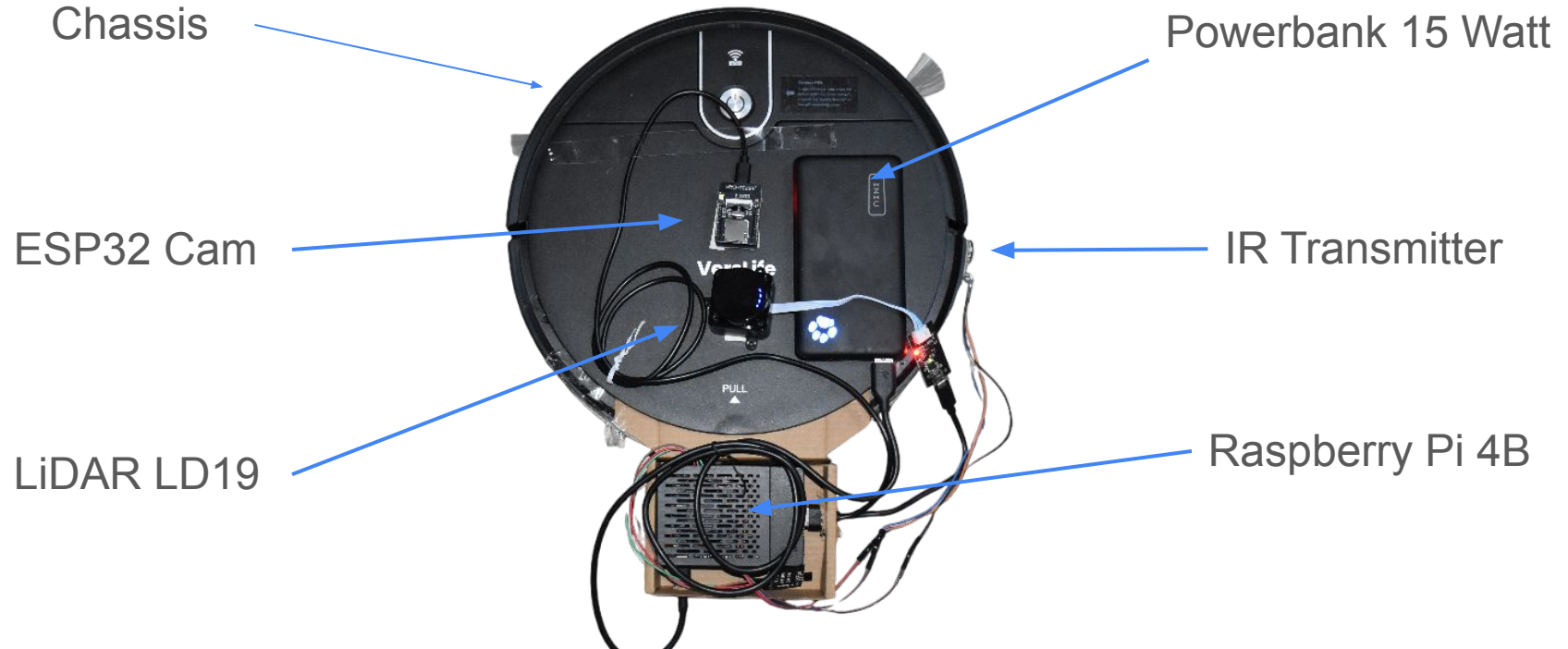
- Limited integration with IoT ecosystems.
- Closed platform.

Objective

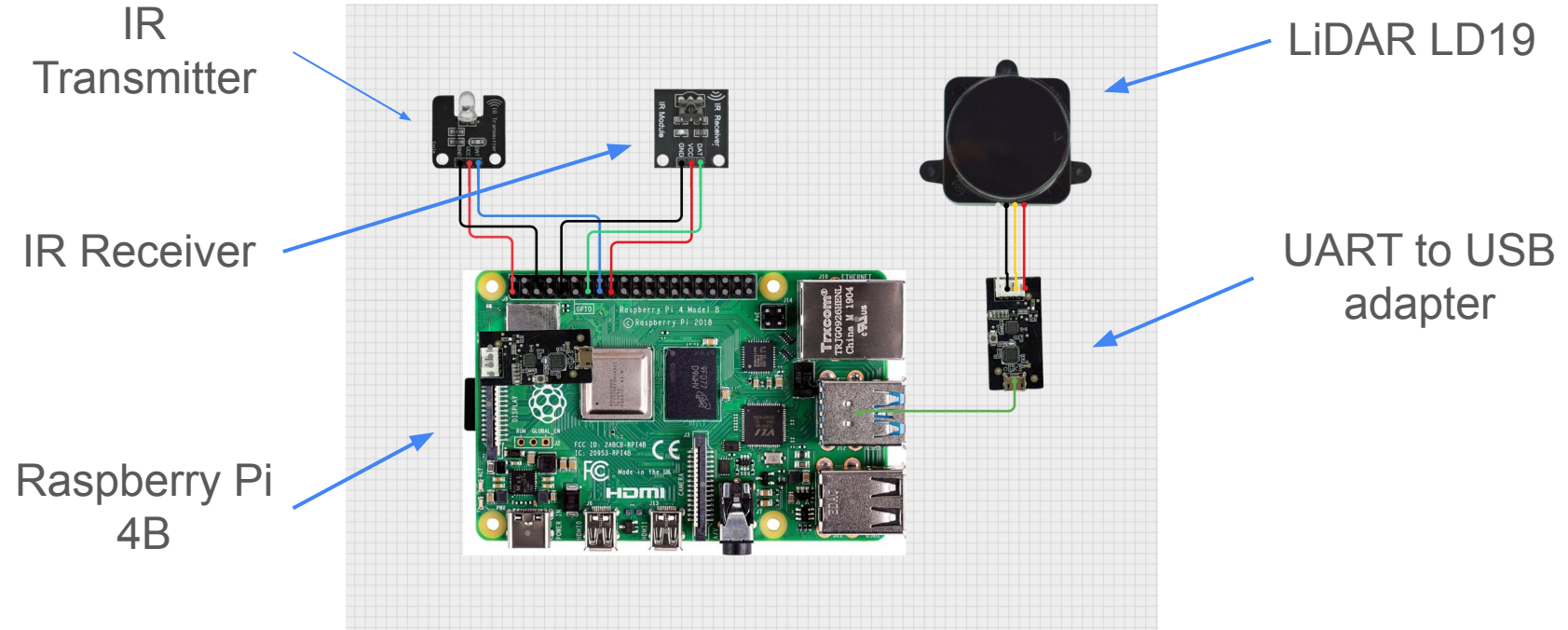
Modify a cheap cleaning robot in order to:

- Extend its capabilities.
- Integrate it inside an IoRT system.

Robot Hardware Design



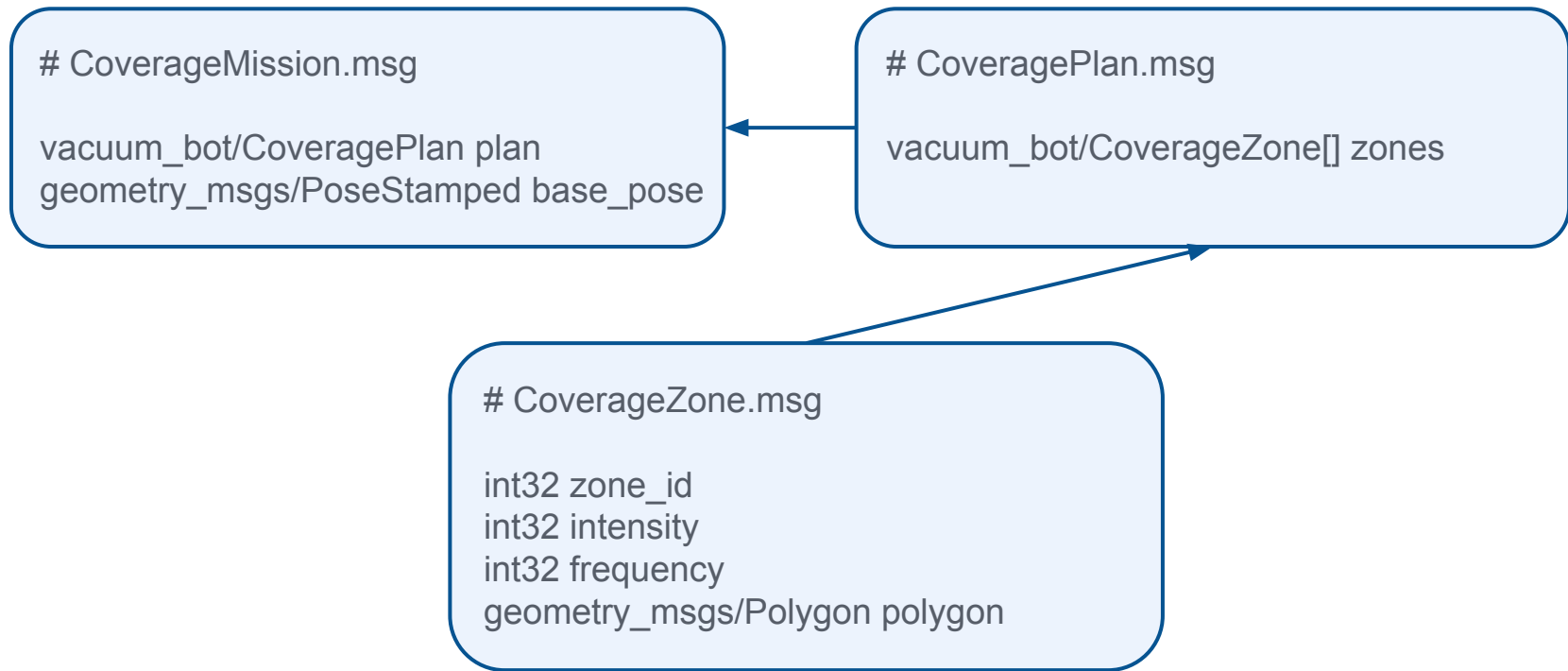
Robot Hardware Design



ROS2 Software Stack

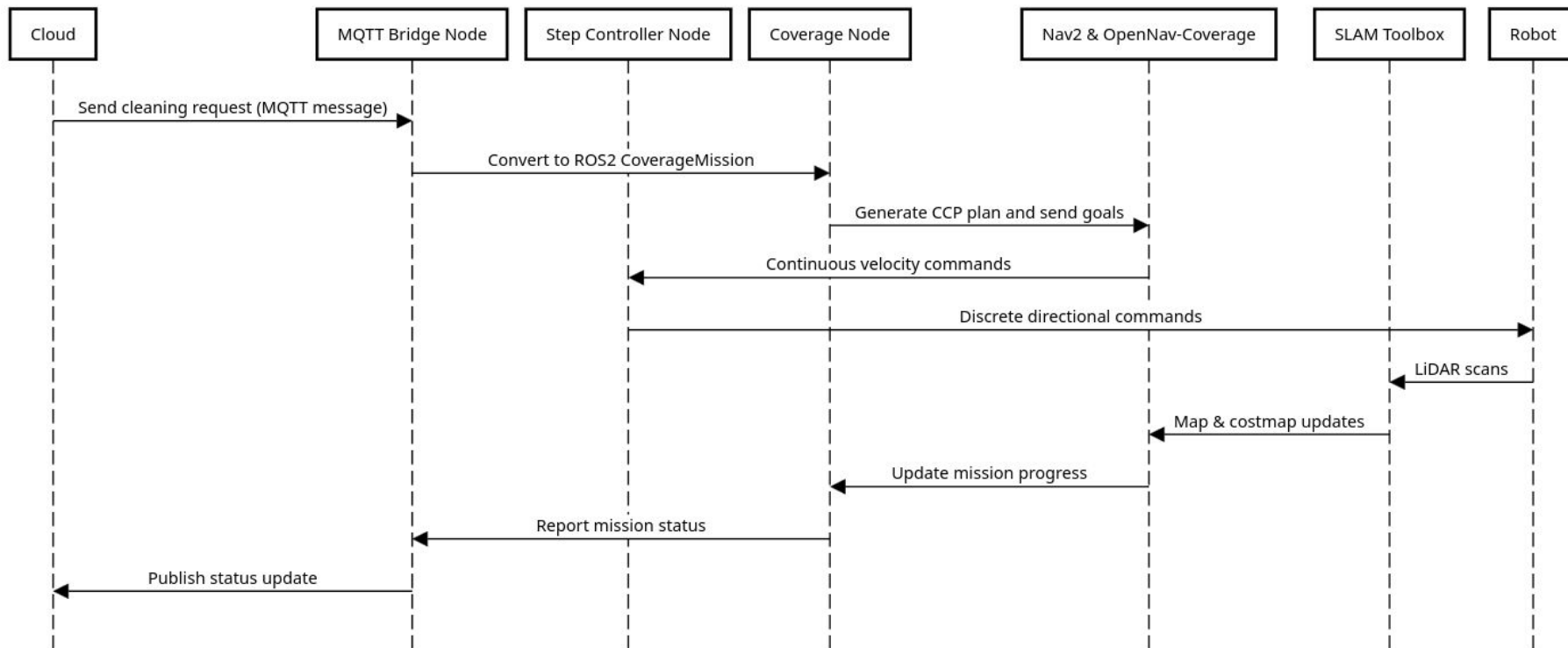
- **Step controller node:** maps continuous velocity commands from Nav2 to discrete directional commands.
- **MQTT bridge node:** converts MQTT messages to ROS2 messages, and viceversa.
- **Coverage node:** accepts a CoverageMission message and create a CCP plan.
- **Nav2 & Opennav-Coverage:** libraries to navigate autonomously and follow a CCP plan.
- **SLAM Toolbox:** generates and publishes a map and costmap based on the LiDAR scans.

CoverageMission Custom Message



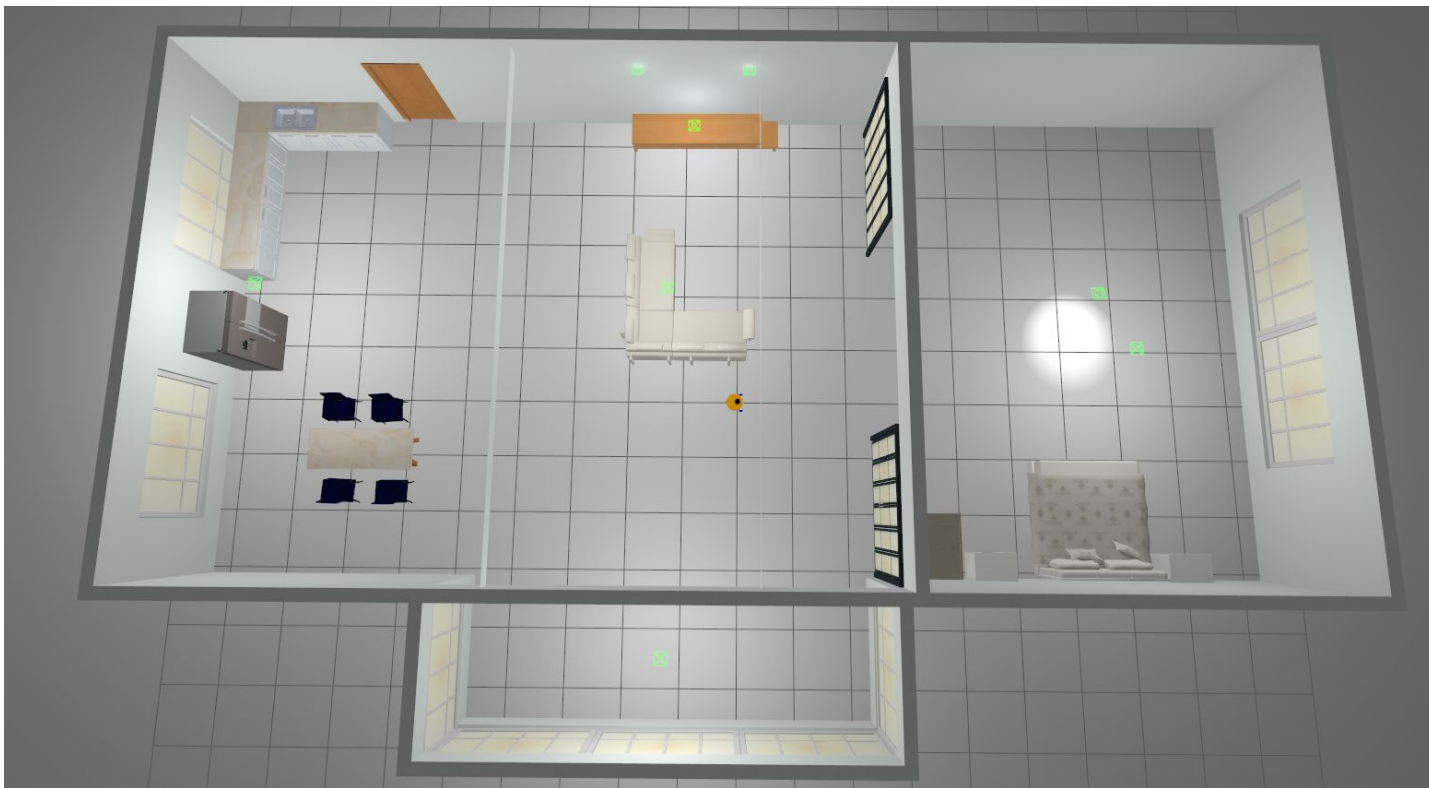
ROS2 Internal Communication

Robot Software Communication



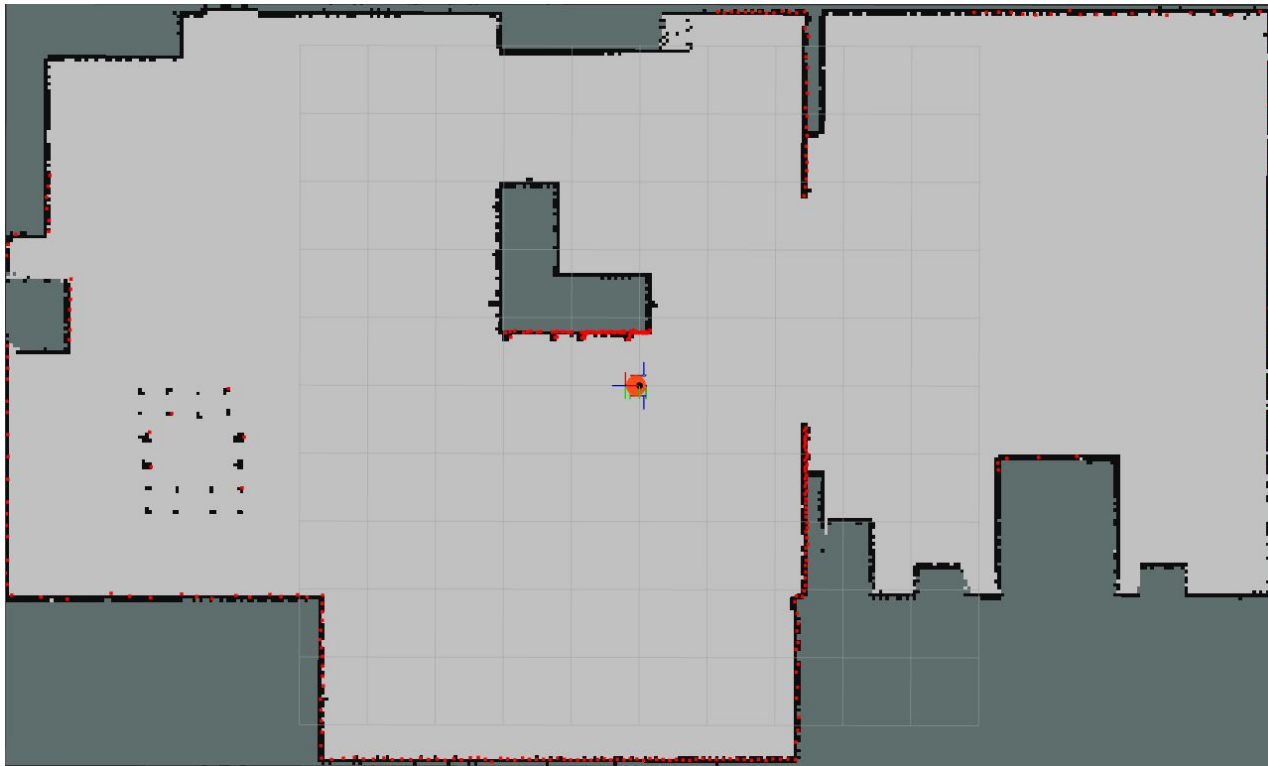
Simulation Software: Gazebo

What the robot **sees**.

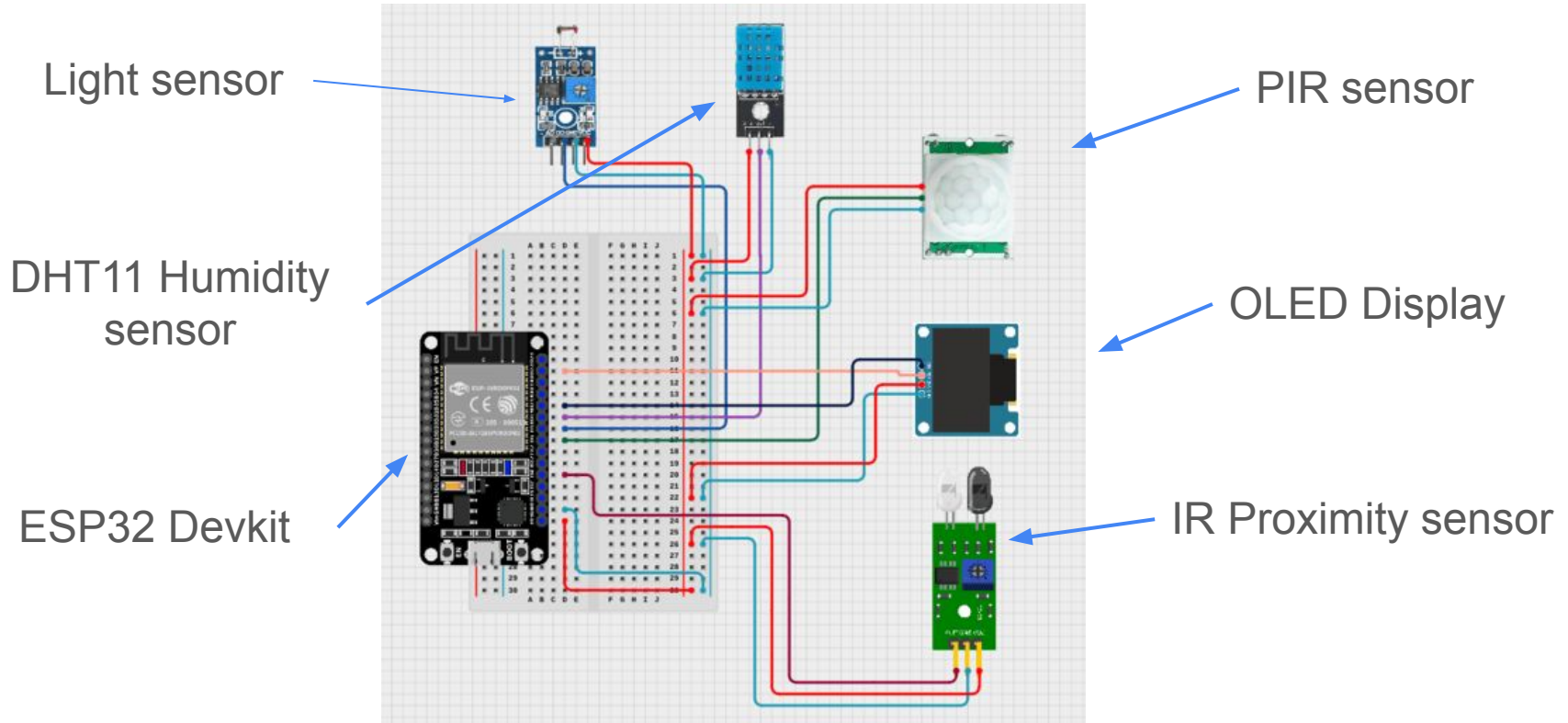


Visualization Software: Rviz

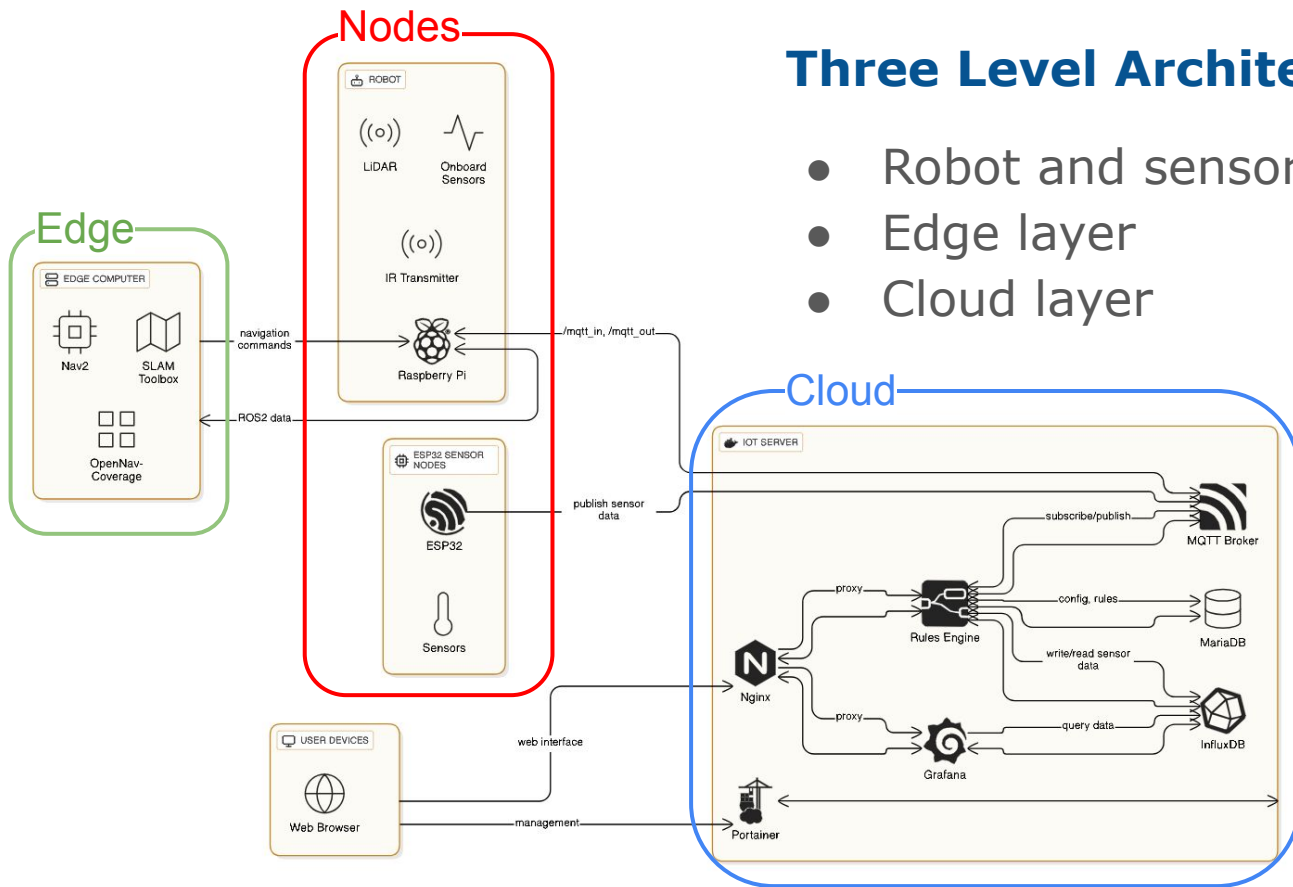
What the robot **thinks**.



IoT Environmental Sensing



IoRT System Design



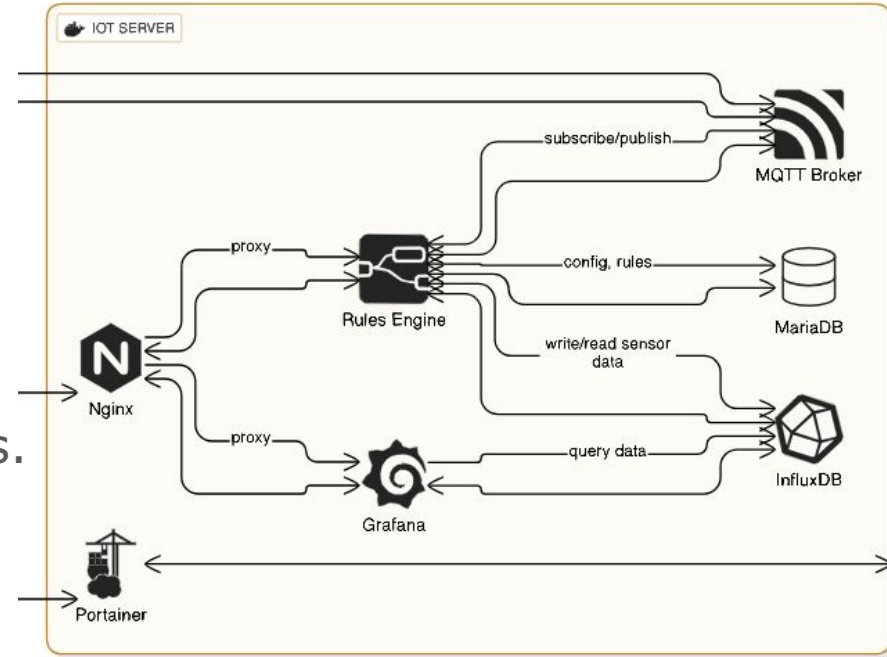
Three Level Architecture:

- Robot and sensors layer
- Edge layer
- Cloud layer

Docker Containers

Containers

1. **Node-RED:** data flow management.
2. **Mosquitto:** MQTT broker.
3. **InfluxDB:** saves sensor data.
4. **Grafana:** visualizes sensor data.
5. **MariaDB:** save user configurations.
6. **Nginx:** reverse proxy and web server.
7. **Portainer:** containers dashboard.

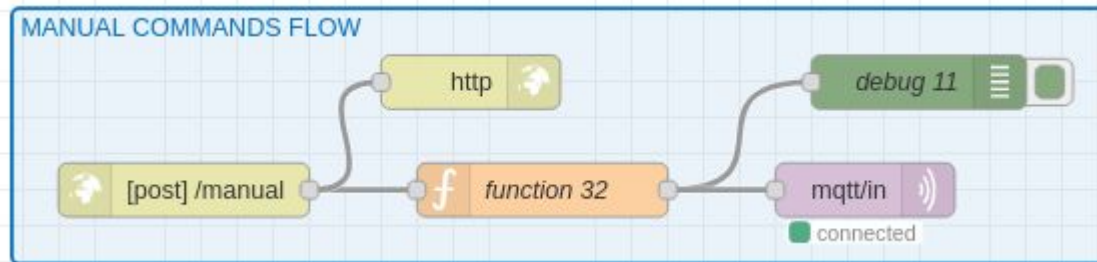


Node-RED Flows (1)

Save sensor data

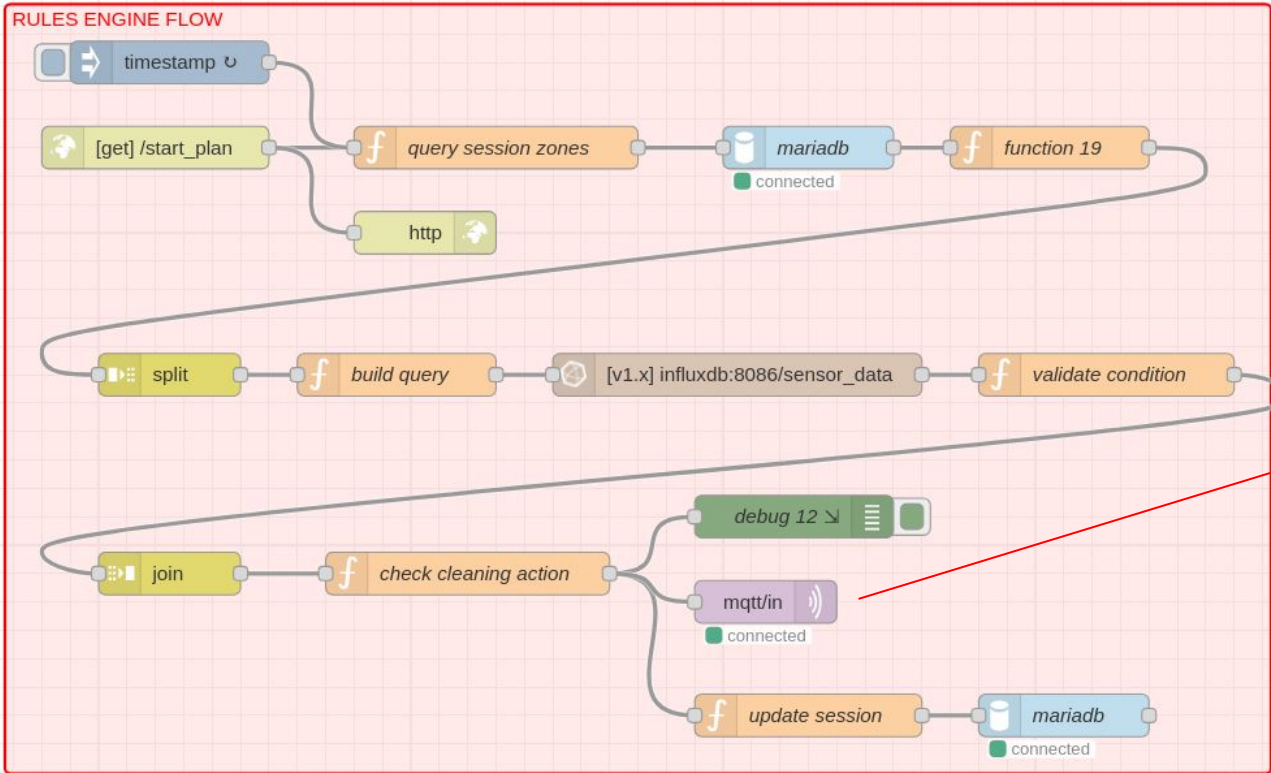


Proxy robot manual commands



Node-RED Flows (2)

Check cleaning sessions and rules

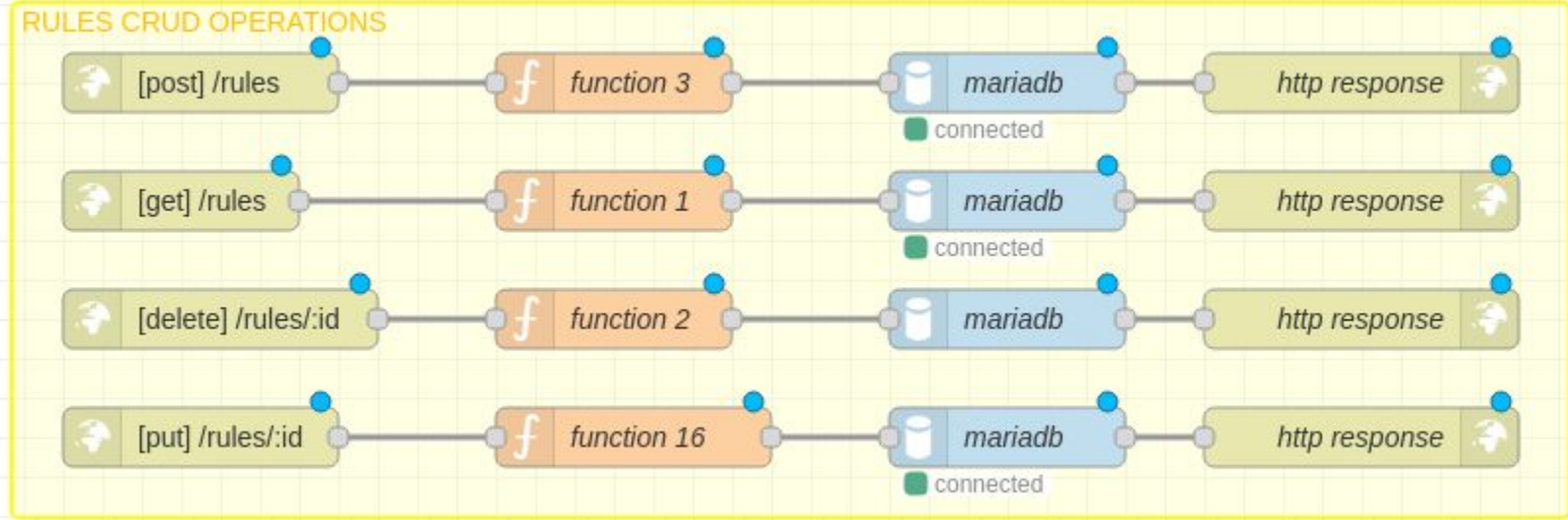


JSON Plan Message

```
{
  "type": "plan",
  "zones": [
    {
      "zone_id": 2,
      "intensity": 1,
      "frequency": 1,
      "ros_points": [...]
    },
    ...
  ],
  "ros_base_pos": {
    "x": -1.62,
    "y": -5.11
  }
}
```

Node-RED Flows (3)

CRUD operations



Web Interface: Map Control Page



Web Interface: Sessions Page

Controllo Mappe

Controllo Manuale

Gestione Sessioni

Sessioni

+ Aggiungi sessione

ID	Nome	Robot	Inizio programmato	Stato	Actions
3	Afternoon cleaning	Vacuum Robot 1	9/8/2025, 5:00:00 PM	scheduled	<div>Modifica</div> <div>Elimina</div>
11	Night cleaning	Vacuum Robot 1	9/10/2025, 2:03:00 AM	scheduled	<div>Modifica</div> <div>Elimina</div>

Regole

+ Aggiungi regola

Name	Sensor	Session	Robot	Zone	Operation	Condition	Value	Interval	Action	Actions
Humidity Check	humidity	Afternoon cleaning	Vacuum Robot 1	Entrance	MEAN	GREATER_THAN	50.00	2h	INTENSITY_3	<div>Modifica</div> <div>Elimina</div>
Motion Check	piDetection	Afternoon cleaning	Vacuum Robot 1	Bedroom	SUM	LESS_THAN	1.00	5s	START_CLEANING	<div>Modifica</div> <div>Elimina</div>
Door IR Check (Low)	obstacleDetection	Afternoon cleaning	Vacuum Robot 1	Living room	SUM	GREATER_THAN	5.00	5s	INTENSITY_2	<div>Modifica</div> <div>Elimina</div>
Door IR Check (High)	obstacleDetection	Afternoon cleaning	Vacuum Robot 1	Living room	SUM	GREATER_THAN	10.00	10s	FREQUENCY_2	<div>Modifica</div> <div>Elimina</div>
Door IR Check (High)	obstacleDetection	Afternoon cleaning	Vacuum Robot 1	Living room	SUM	GREATER_THAN	10.00	10s	INTENSITY_2	<div>Modifica</div> <div>Elimina</div>
Luminosity Check	luminosity	Afternoon cleaning	Vacuum Robot 1	Bedroom	LAST	EQUAL	0.00	10s	INTENSITY_1	<div>Modifica</div> <div>Elimina</div>

Sensori

+ Aggiungi sensore

ID	Nome	Actions
11	humidity	<div>Modifica</div> <div>Elimina</div>
12	luminosity	<div>Modifica</div> <div>Elimina</div>
13	piDetection	<div>Modifica</div> <div>Elimina</div>
14	obstacleDetection	<div>Modifica</div> <div>Elimina</div>
15	temperature	<div>Modifica</div> <div>Elimina</div>

Robot

+ Aggiungi robot

ID	Nome	Actions
17	Vacuum Robot 1	<div>Modifica</div> <div>Elimina</div>

Use Cases

- **Motion detection:** start cleaning when the room is empty (no PIR detections).
- **Adapt to weather conditions:** use humidity readings to try and predict raining conditions. Increase intensity near entrance.
- **Room activity level:** increase cleaning intensity if door passages cross over a user defined limit.
- **Night mode:** use minimum intensity when light goes below a certain threshold to not disturb sleep.

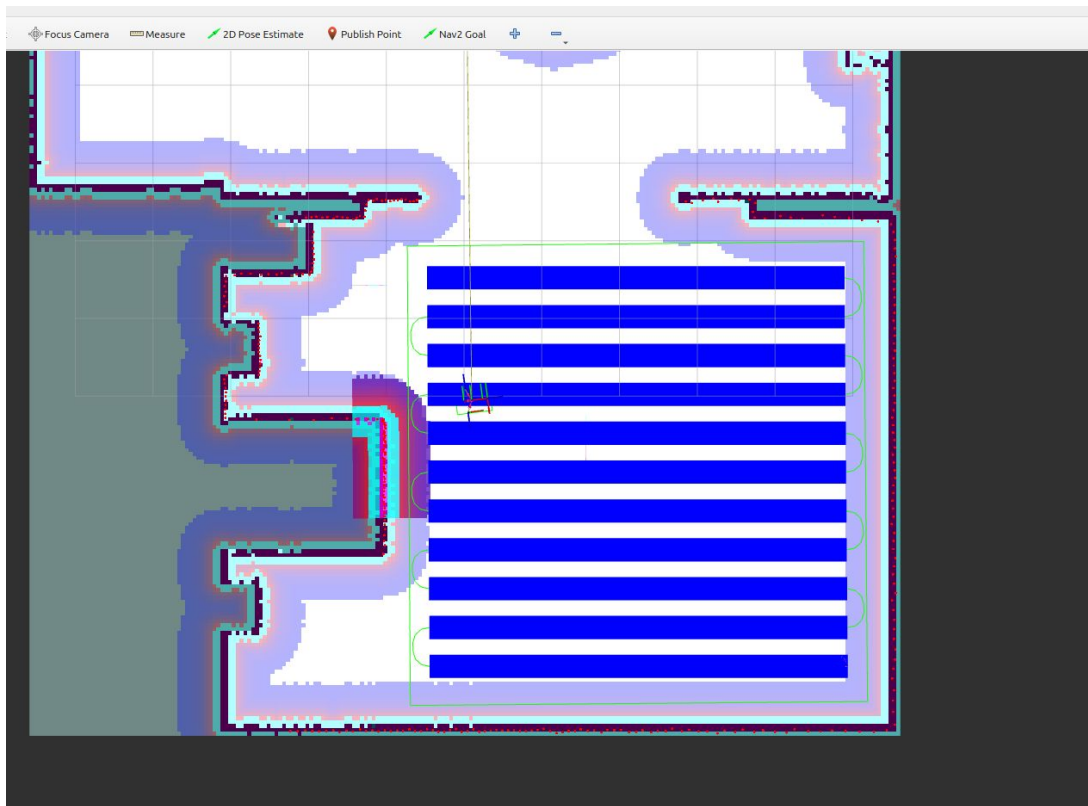
Results

No PIR detections in the time period.

START CLEANING.

First room: Bedroom.

Default intensity and frequency levels.

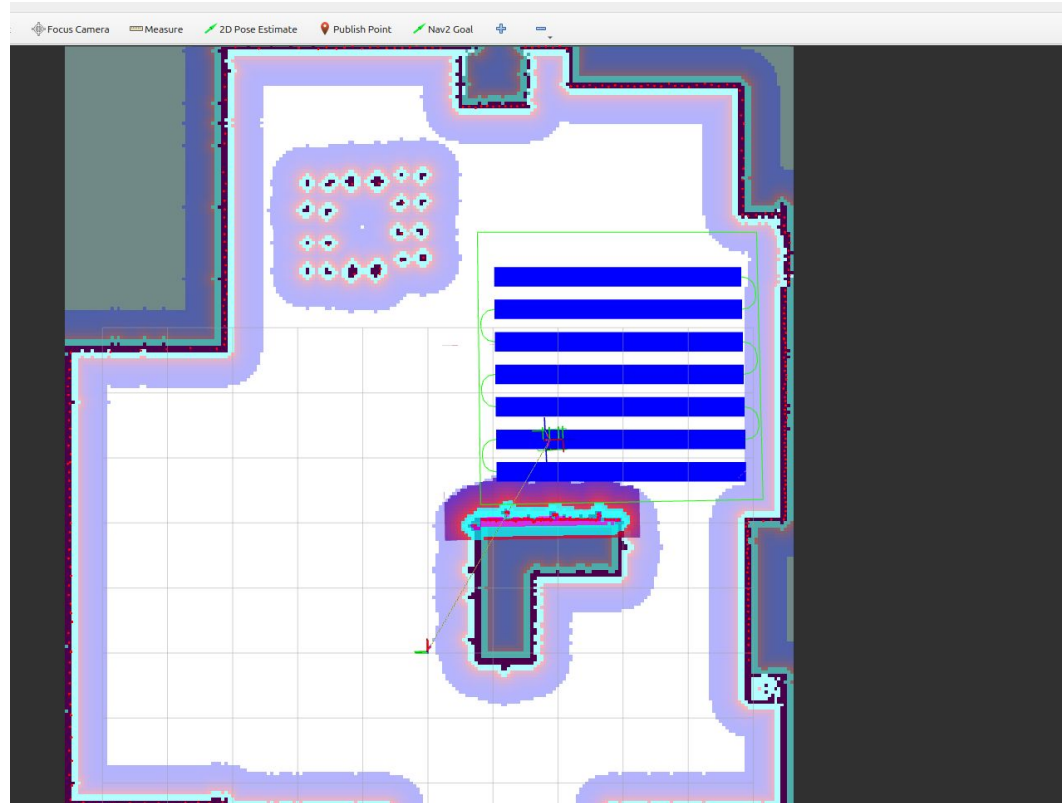


Results

Second room:
Entrance.

Humidity level greater
than threshold.

INTENSITY = 3.

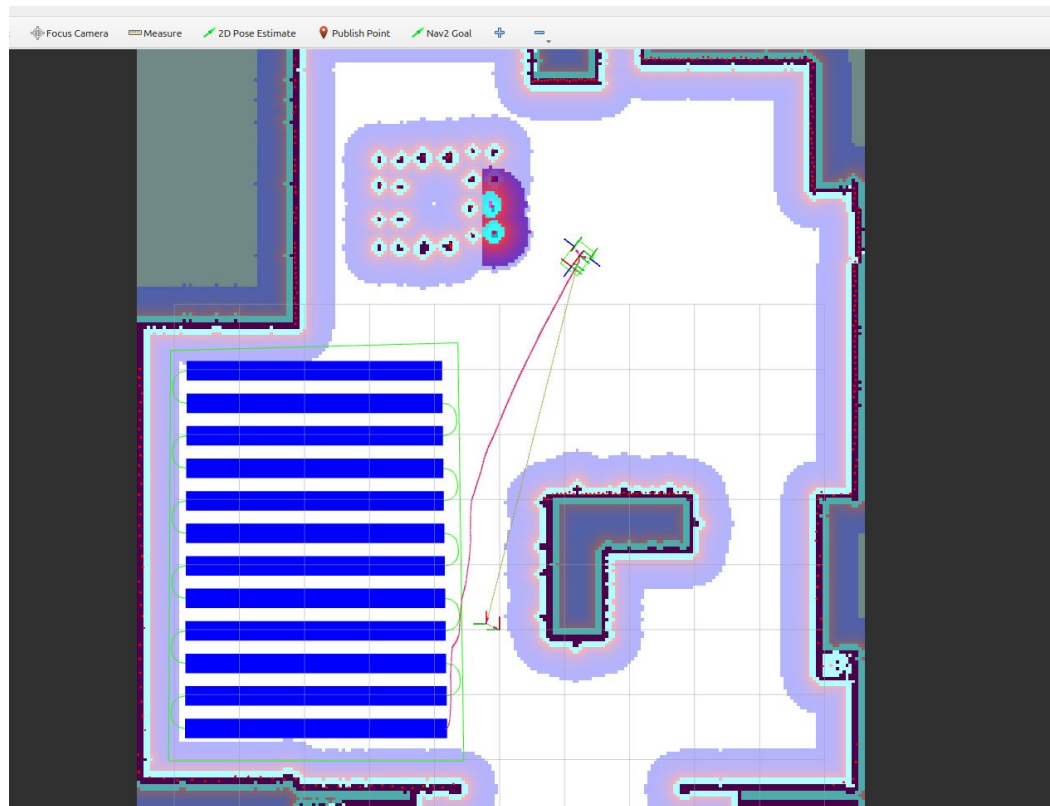


Results

Third room:
Living room.

Number of passage
detections greater
than threshold.

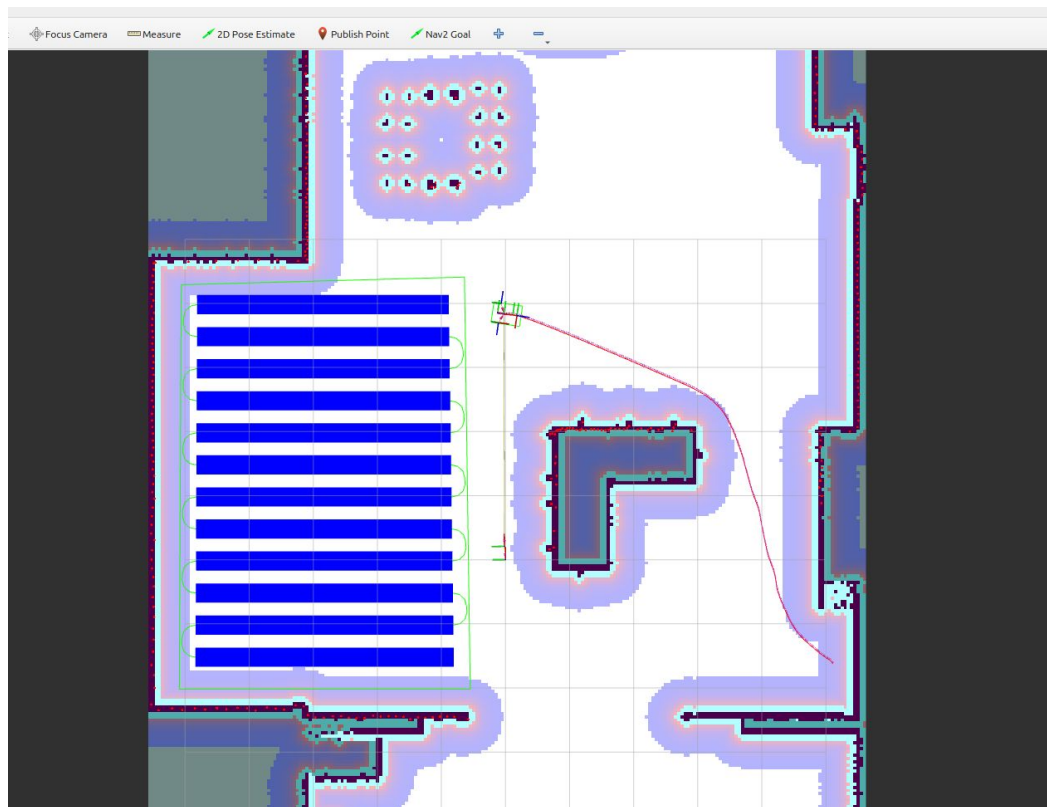
INTENSITY = 3.
FREQUENCY = 2.



Results

No more rooms.

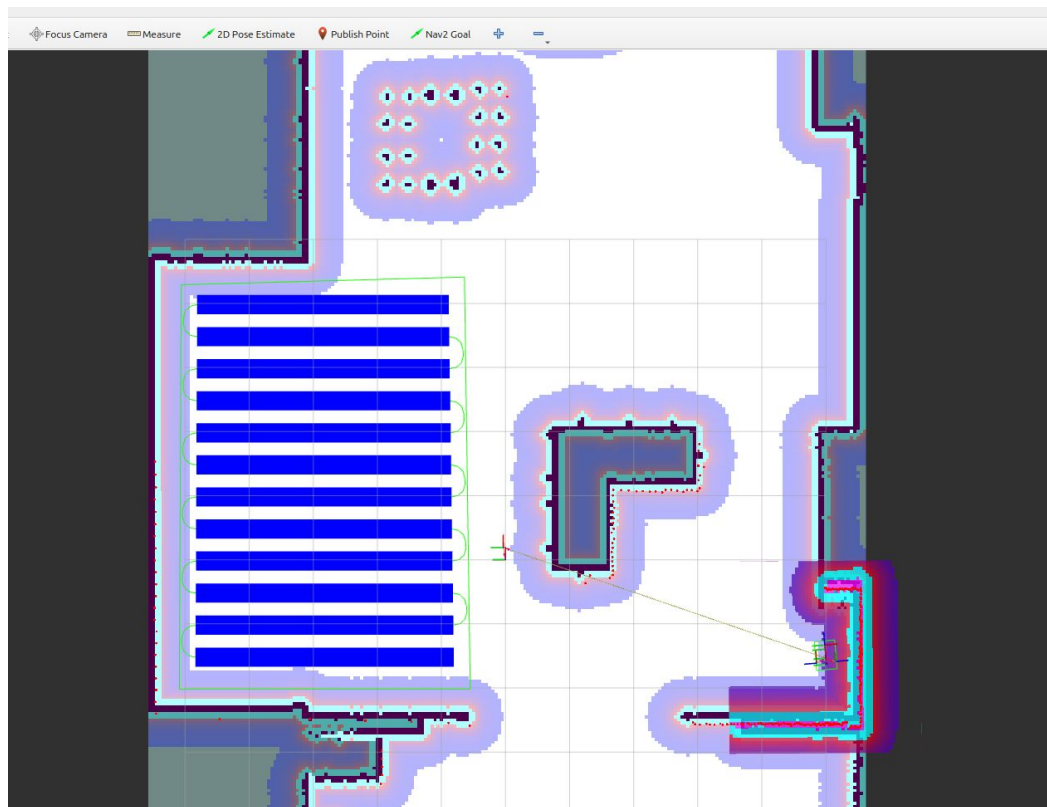
RETURN TO BASE.



Results

Reached base station.

STOP.



Conclusion and Future Work

Conclusions

- Demonstrated the IoRT paradigm applied to automated cleaning.
- Enhanced a low-cost vacuum robot with additional components and ROS integration.
- Developed a system for event-based cleaning rules.

Future directions

- Machine learning for context-aware cleaning (e.g., RL).
- Multi-robot collaboration.
- Explore more resilient protocols (LoRa, ZigBee, 5G).



Thanks for the attention