Lab 2: ROS Perception System Basics — Image Subscription and Processing

1. Experiment Objectives

- Learn how to subscribe to and process image data (RGB and Depth) in ROS.
- Master basic image processing techniques using OpenCV: Color Space Conversion (HSV), Object Detection, and Contour Detection.
- Understand how to calculate 3D coordinates of objects using Depth maps and Camera Intrinsics.
- Learn to transform coordinates from the Camera Frame to the Robot Base Frame using TF.
- Implement a basic Visual Servoing control loop to follow a target.
- Visualize 3D Point Clouds using Open3D.

2. Prerequisites

- **Hardware**: TurtleBot3 (or simulation), PC with Ubuntu 20.04.
- **Software**: ROS Noetic, Python 3.x, OpenCV, Open3D, `cv_bridge`.
- **Package**: `lab2_perception` (Provided in `src/`).

3. Setup and Compilation

First, ensure your environment is set up and the package is compiled.

```
# 1. Navigate to your workspace
cd ~/catkin_ws

# 2. Build the package
# We whitelist only this package to speed up compilation
catkin_make -DCATKIN_WHITELIST_PACKAGES="lab2_perception"

# 3. Source the setup script to register the new package
source devel/setup.bash
```

4. Step-by-Step Experiment

Part 1: Basic Image Subscription

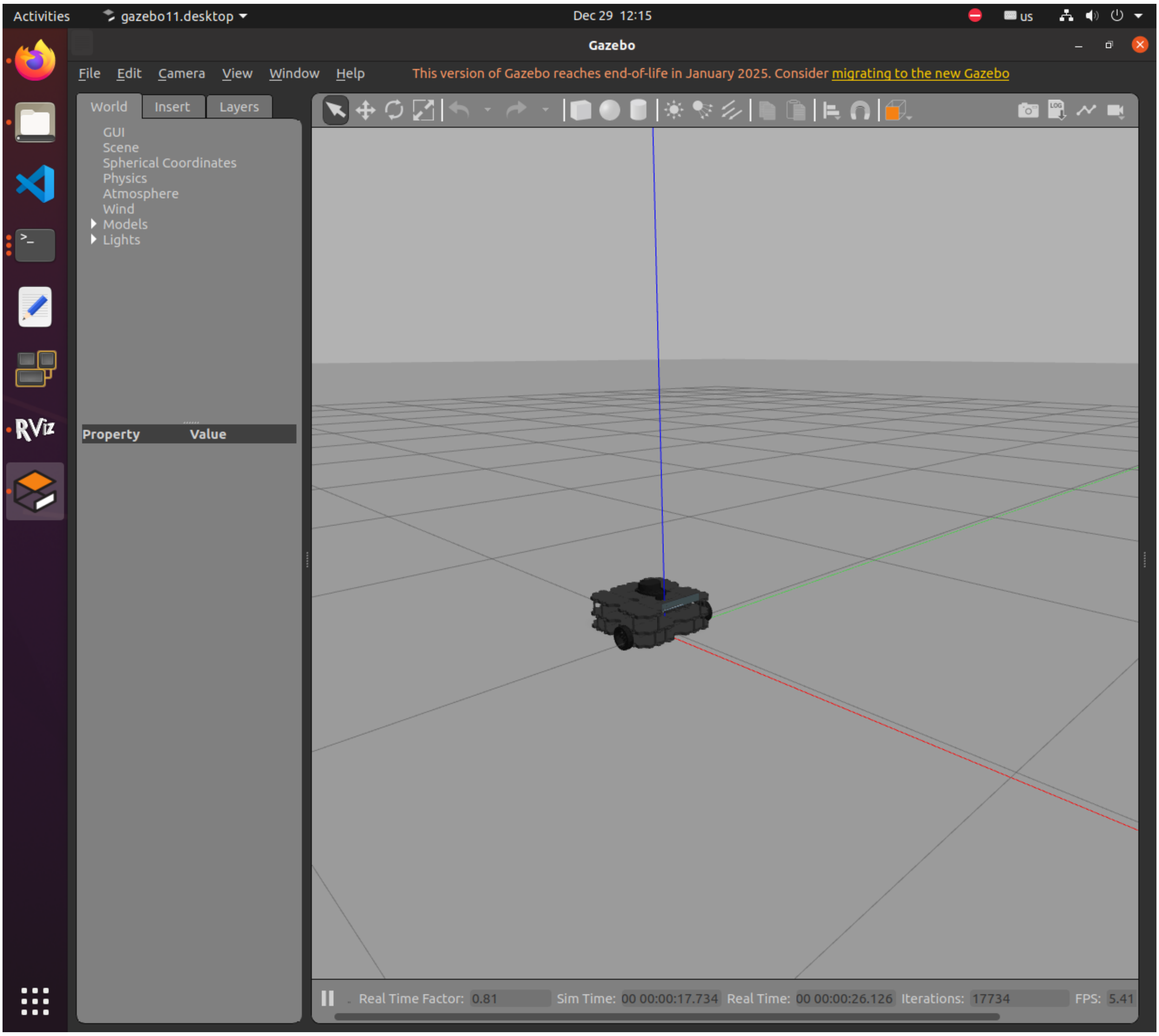
Before diving into complex processing, let's verify we can receive images from the camera.

1.1 Run RGB Subscriber This script subscribes to `/camera/rgb/image_raw` and displays the video stream.

```
# Terminal 1: Start ROS Master (if not running)
roscore

# Terminal 2: Play a bag file or start a camera simulation (if you have one)
source ~/catkin_ws/devel/setup.bash
```

```
export TURTLEBOT3_MODEL=waffle
roslaunch turtlebot3_gazebo turtlebot3_empty_world.launch
```

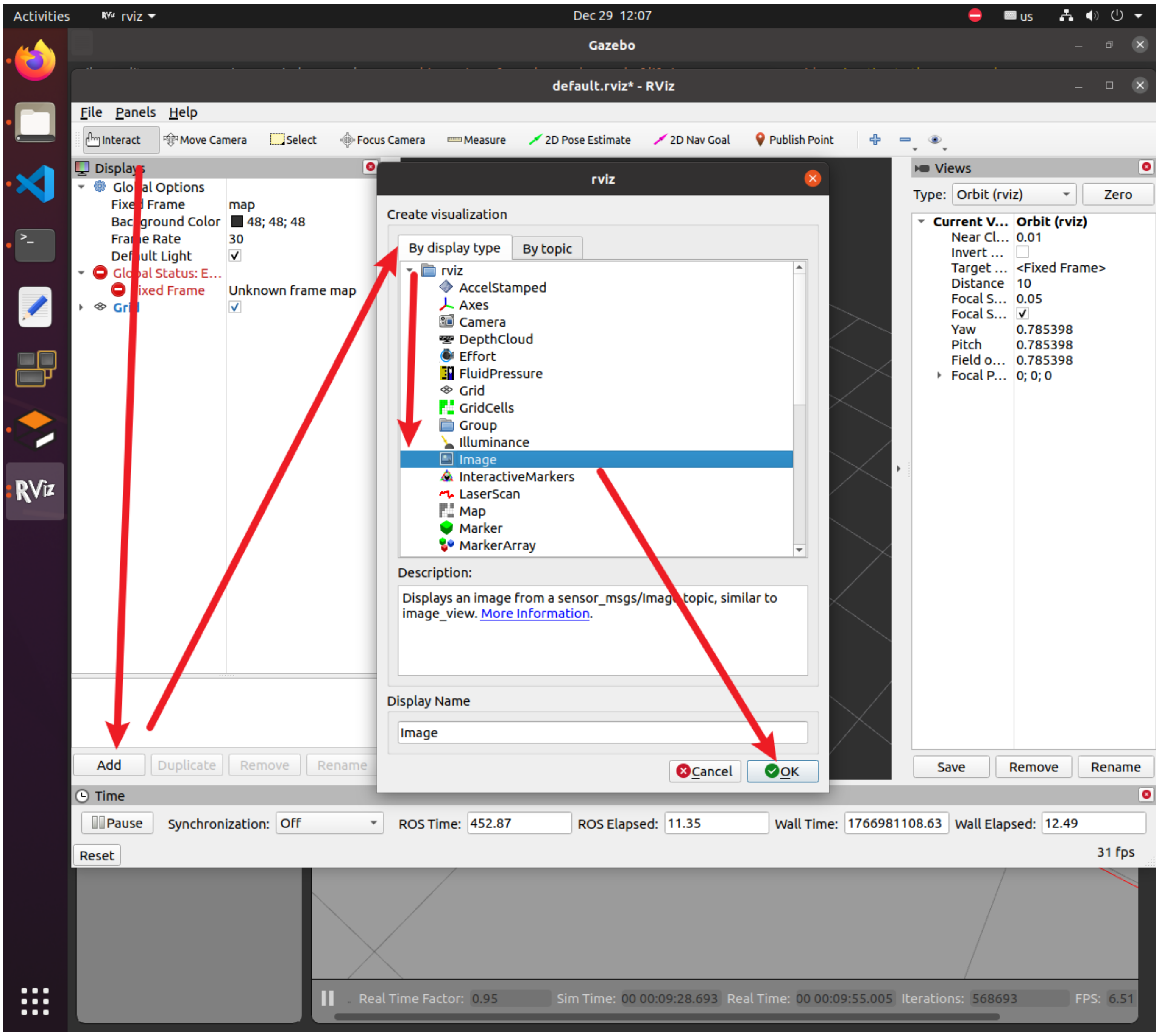


1.2 Run rviz to visualize rgb and depth image

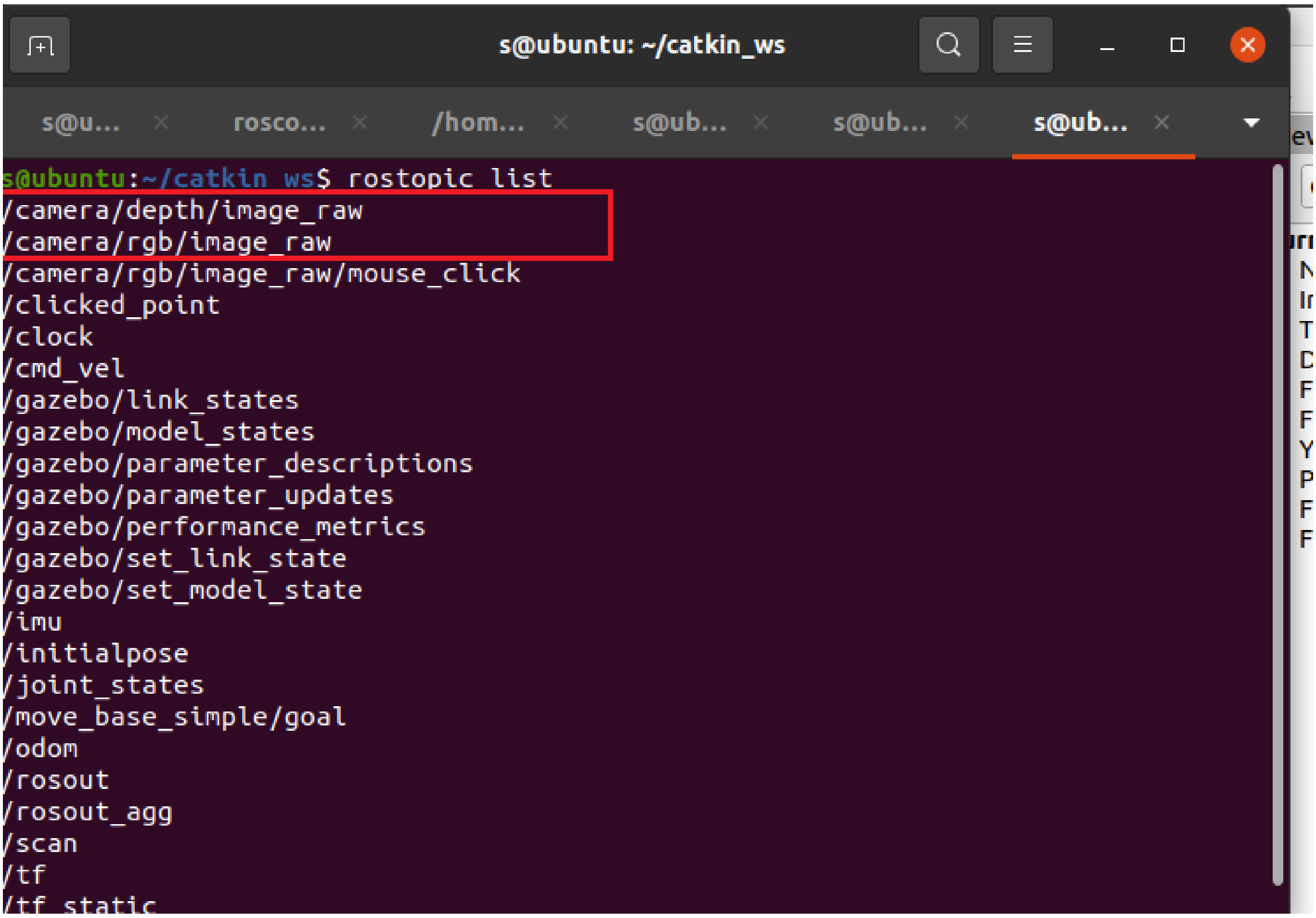
Open RViz and add image displays for both RGB and depth topics.

```
# Terminal 3: Run RViz
rviz
```

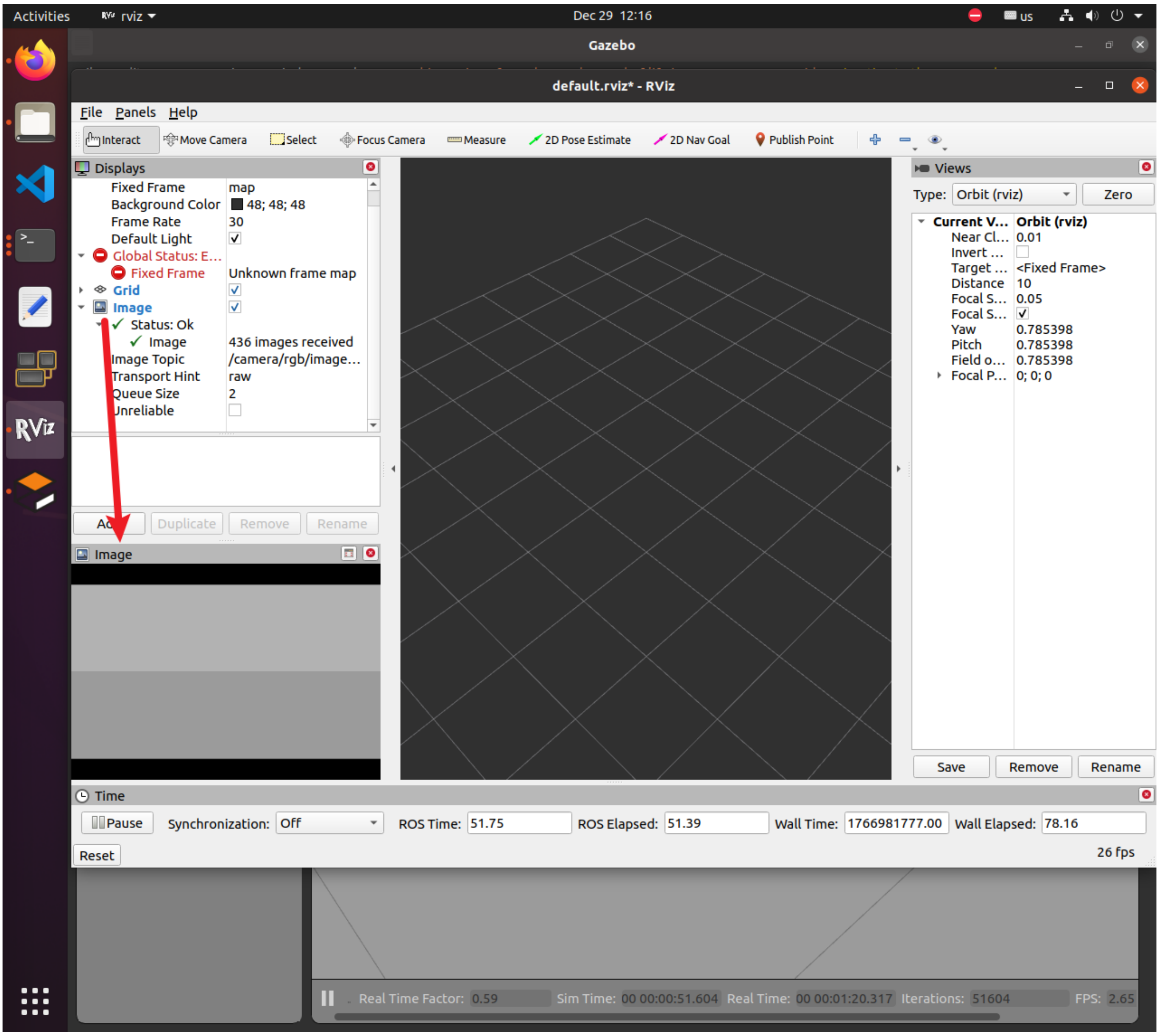
In RViz: Click Add → By display type → Image



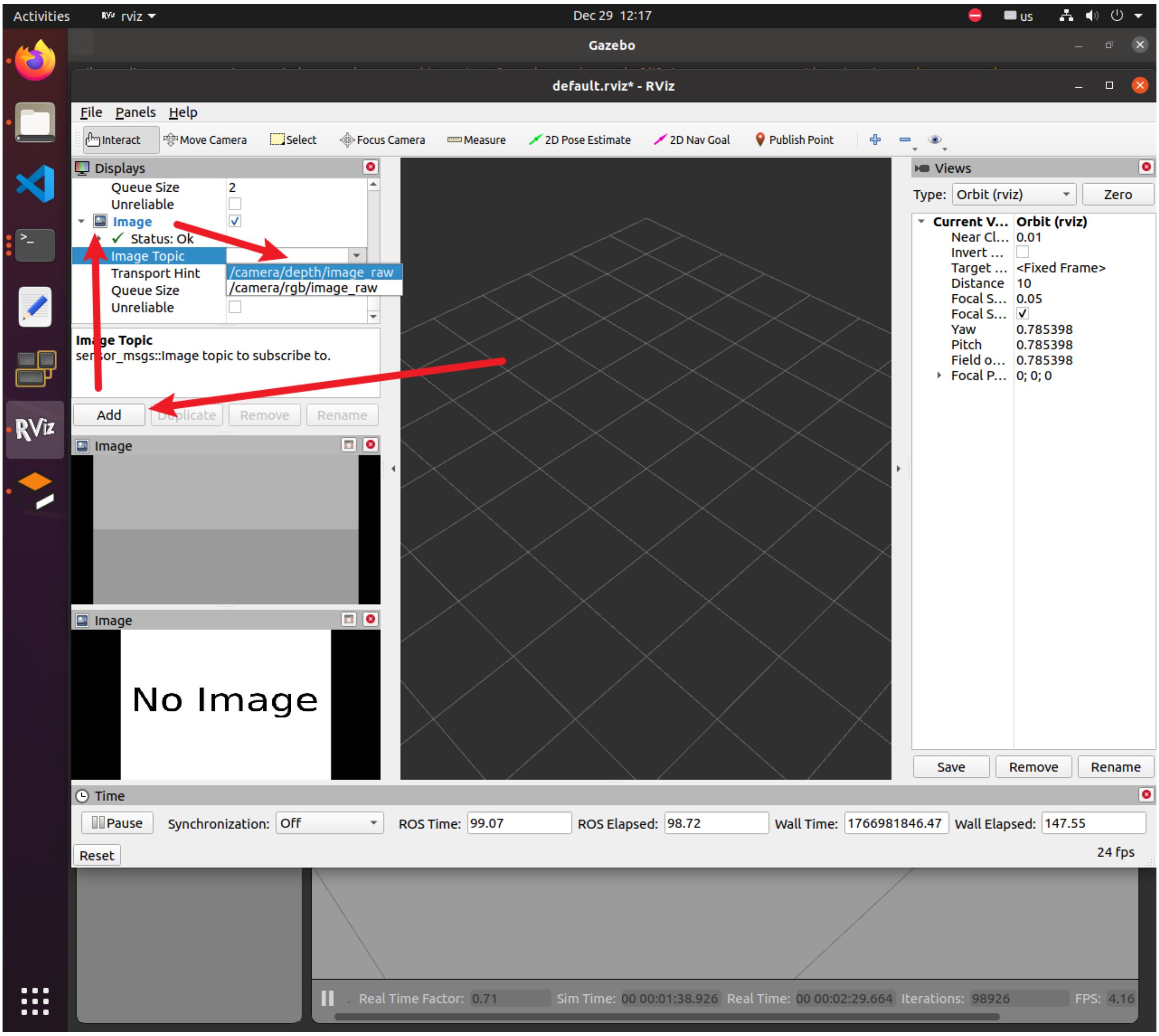
Use `rostopic list` to check the camera topic name.

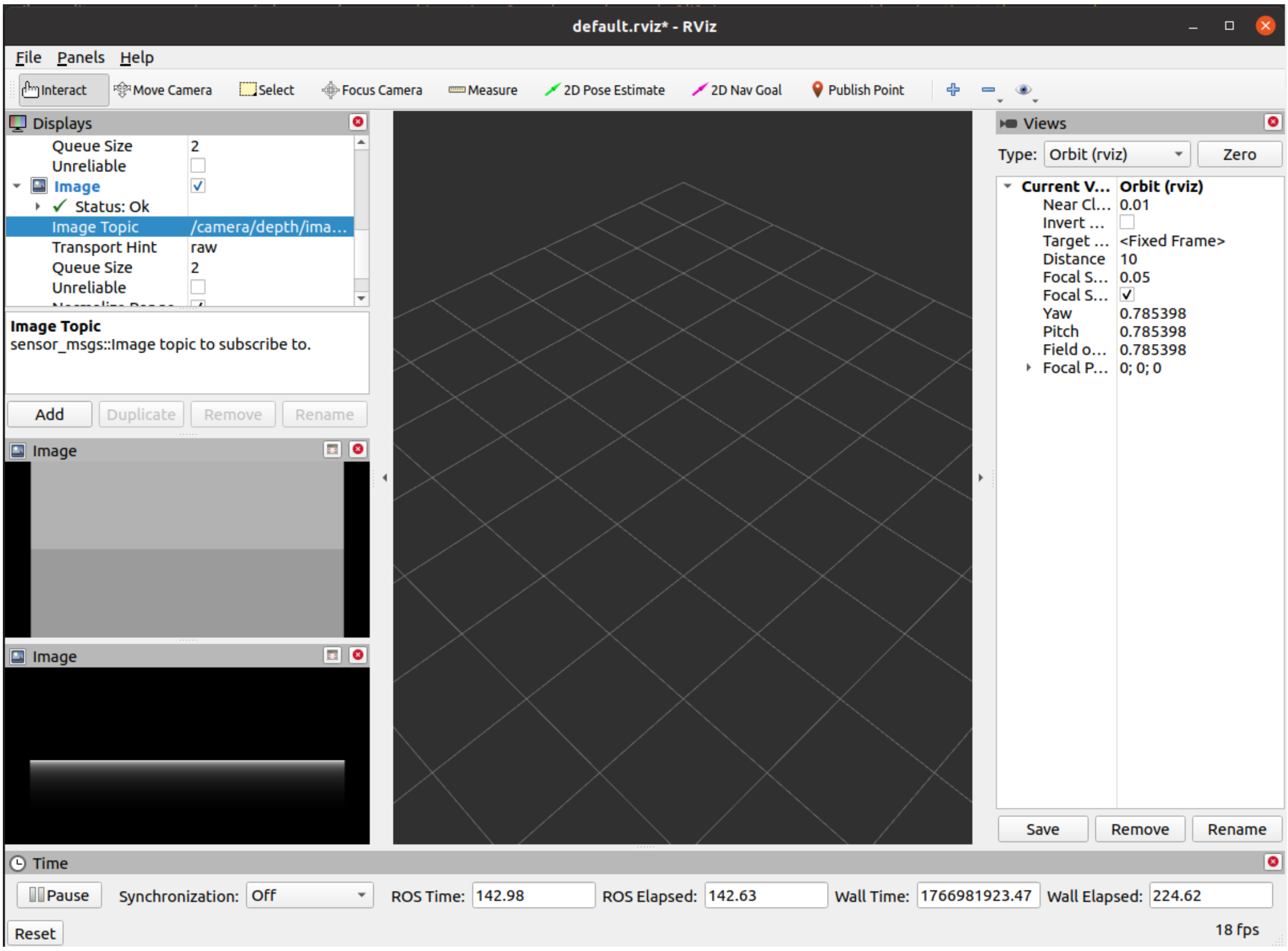


Set the topic to /camera/rgb/image_raw



Add another Image display and set the topic to /camera/depth/image_raw Adjust the Fixed Frame (e.g., camera_link or base_link) if needed This allows you to visually inspect both the RGB stream and the depth map in real time.

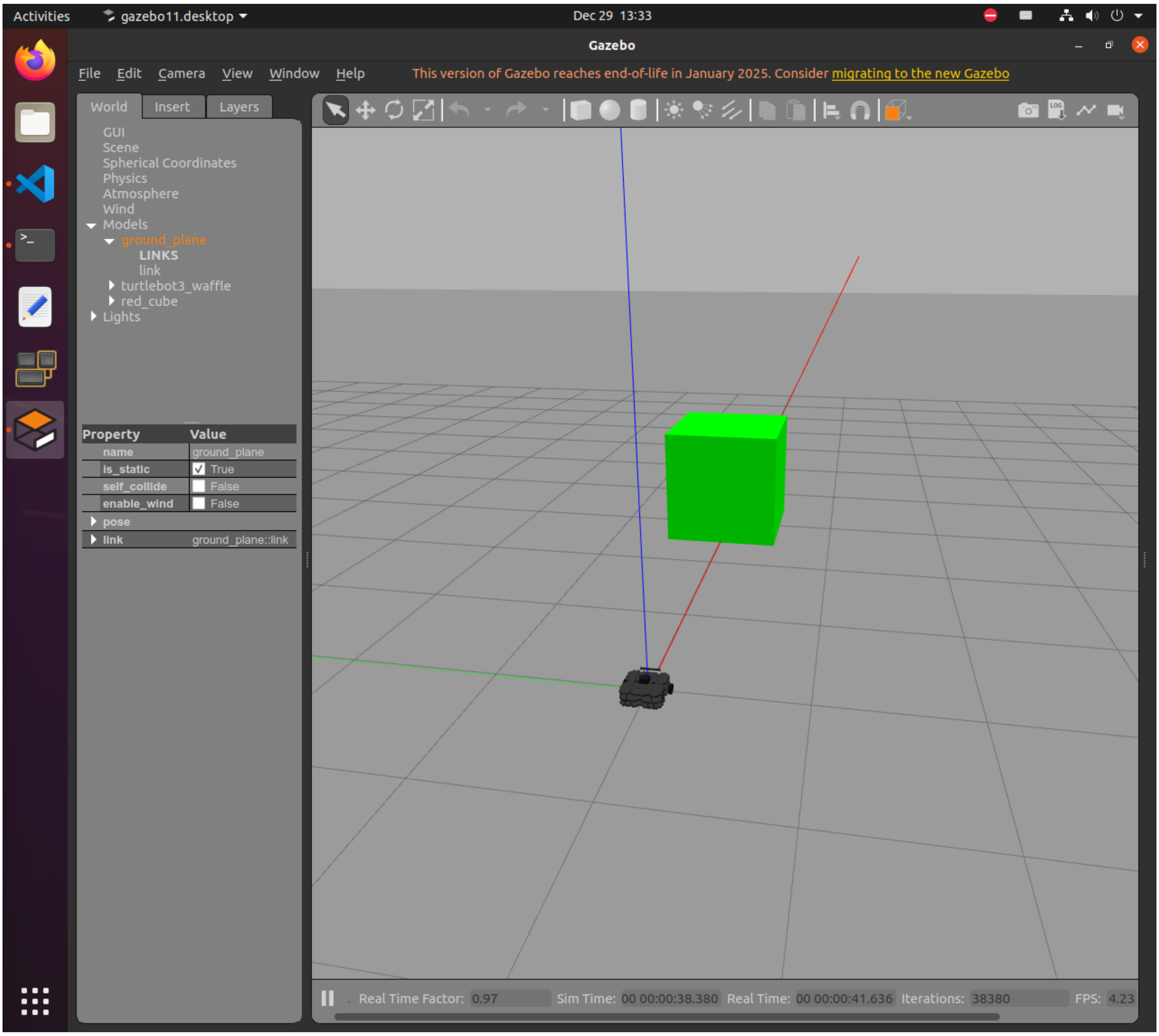

Activities
rviz
Dec 29 12:17
Gazebo
default.rviz* - RViz
File Panels Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Nav Goal
Publish Point
Displays
Queue Size 2
Unreliable
Image
Status: Ok
Image Topic
/camera/depth/image_raw
/camera/rgb/image_raw
Transport Hint
Queue Size
Unreliable
Image Topic
sensor_msgs::Image topic to subscribe to.
Add
Duplicate
Remove
Rename
Image
Image
No Image
Views
Type: Orbit (rviz)
Zero
Current V... Orbit (rviz)
Near Cl... 0.01
Invert ...
Target ... <Fixed Frame>
Distance 10
Focal S... 0.05
Focal S...
Yaw 0.785398
Pitch 0.785398
Field o... 0.785398
Focal P... 0; 0; 0
Save
Remove
Rename
Time
Pause
Synchronization: Off
ROS Time: 99.07
ROS Elapsed: 98.72
Wall Time: 1766981846.47
Wall Elapsed: 147.55
Reset
24 fps
Real Time Factor: 0.71
Sim Time: 00 00:01:38.926
Real Time: 00 00:02:29.664
Iterations: 98926
FPS: 4.16



1.3 Set obstracle for sensor

Set a green cube for object detection:

```
source ~/catkin_ws/devel/setup.bash
rosrun gazebo_ros spawn_model \
  -file ~/catkin_ws/src/lab2_perception/demo_images/red_cube.sdf \
  -sdf \
  -model red_cube
```



Part 2: Image Processing Tools (HSV Tuning)

To detect a specific object (like a red block), we need to find the correct HSV (Hue, Saturation, Value) thresholds. We have provided tools to help you with this.

2.1 Generate Test Images First, let's generate some sample images to test our algorithm.

```
# Generate dummy images in src/lab2_perception/demo_images/
rosrun lab2_perception generate_images.py
```

2.2 Tune HSV Thresholds Use the tuner tool to find the best values to isolate the red color.

```
# Run the tuner tool
rosrun lab2_perception hsv_tuner.py
```

Instructions:

1. Use the "Image" trackbar to switch between the generated images.
2. Adjust `H Min`, `S Min`, `V Min`, etc., until only the desired object is white in the middle mask window.
3. **Record these values**. You will need them for the main perception node. (Default values for red are already set in the code).

Part 3: Integrated Perception & Visual Servoing

This is the core of the experiment. We will run the TurtleBot3 simulation in Gazebo. The robot will use its camera to detect a red object, calculate its 3D position, and drive towards it.

3.1 Launch Simulation and Perception Node

We have prepared a launch file that starts:

- Gazebo with TurtleBot3.
- The `perception_node` (performs detection and control).
- RViz for visualization.

```
# Close previous terminals if needed, then run:
roslaunch lab2_perception lab2.launch
```

3.2 What to Observe

1. **Gazebo**: You should see the TurtleBot3 in an empty world.
   - *Action*: Insert a Red Box (or Cylinder) in front of the robot.
   - Go to the "Insert" tab in Gazebo -> `http://gazebosim.org/models/` -> `Unit Box`.
   - Right-click the box -> `Edit model` -> Change color to Red (or just assume the default code detects the generated samples if you can spawn a red object).
   - *Alternative*: If you cannot spawn a red object easily, the code defaults to looking for "Red". Ensure you have something red in the camera view.
2. **OpenCV Windows**:
   - **Original RGB**: Shows the camera view with the detected object circled and its (X, Y, Z) coordinates displayed.
   - **HSV Result**: Shows the binary mask of the detected color.
   - **Canny Edges**: Shows edge detection results.
3. **Visual Servoing**:
   - If a red object is detected, the robot should rotate to face it and move closer until it is 0.5m away.

3.3 Data Visualization in Terminal To see the custom messages being published:

```
# Open a new terminal
source ~/catkin_ws/devel/setup.bash

# Check the detected object coordinates
rostopic echo /detected_object
```

```
# Check the velocity commands being sent to the robot
rostopic echo /cmd_vel
```

Part 4: 3D Point Cloud Visualization

We can also visualize the depth data as a 3D Point Cloud using the Open3D library.

4.1 Run the Visualizer While the simulation (from Part 3) is running:

```
# Open a new terminal
source ~/catkin_ws/devel/setup.bash

# Run the Open3D visualizer
rosrun lab2_perception pointcloud_visualizer.py
```

Instructions:

- A new window "3D Point Cloud" will appear.
- **Left Click + Drag**: Rotate the view.
- **Right Click + Drag**: Pan the view.
- **Scroll Wheel**: Zoom in/out.
- You should see the 3D reconstruction of the scene in front of the robot.

Part 5: TF Coordinate Transformation

The `perception_node` automatically broadcasts the position of the detected object in the robot's coordinate system.

1. **RViz**:
    - The launch file opens RViz.
    - Ensure "TF" is checked in the display list.
    - You can visualize the relationship between `camera_rgb_optical_frame` (where the camera sees) and `base_footprint` (the robot's center on the ground).
    - The code calculates the object's position in `base_footprint` and logs it (check the node output).

5. Summary of Key Commands

Task	Command
Build	`catkin_make -DCATKIN_WHITELIST_PACKAGES="lab2_perception"`
Generate Images	`rosrun lab2_perception generate_images.py`
HSV Tuner	`rosrun lab2_perception hsv_tuner.py`

Task	Command
Launch Lab	`roslaunch lab2_perception lab2.launch`
3D Visualizer	`rosrun lab2_perception pointcloud_visualizer.py`
Check Topics	`rostopic echo /detected_object`

6. Troubleshooting

- **"ModuleNotFoundError: No module named 'open3d'"**: Install Open3D via pip:

```
pip install open3d
```

- **Robot spins in circles**: Check if the red object is visible. If not, the robot stops (or keeps last command depending on logic). Ensure the HSV thresholds match your object.
- **Camera not working**: Ensure Gazebo is running and not paused.