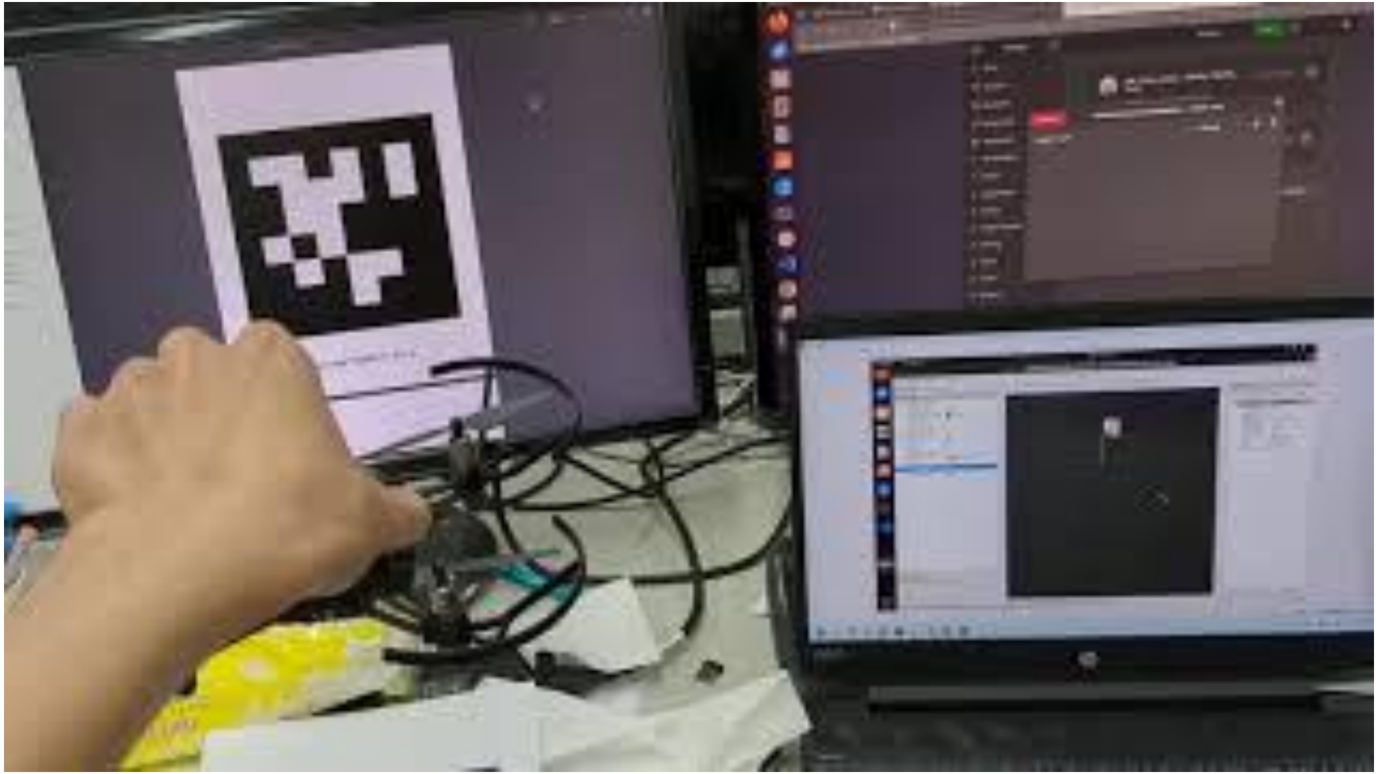
State Estimation Lab

Lab 1

Overview

- **ROS2 Introduction**
- Coordinate Systems (Extrinsic, Intrinsic Matrix)
- AprilTag, Calibration application
- Lab
  - 1.1 Get camera's intrinsic matrix and distortion coefficient.
  - 1.2 Run Tello driver to see drone streaming.
  - 1.3 Pose estimation using single AprilTag.

Today's Goal



2025 HCC State Estimation Lab1 test

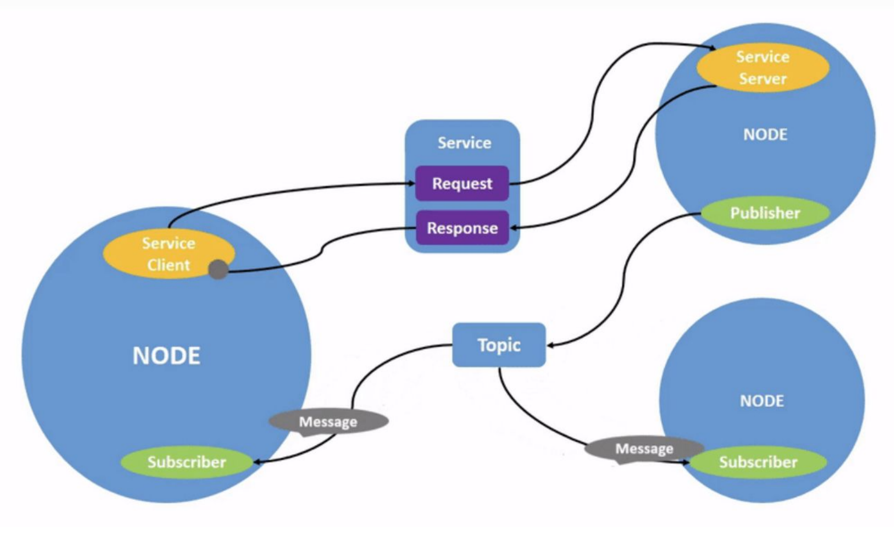
What is ROS? Why use ROS?

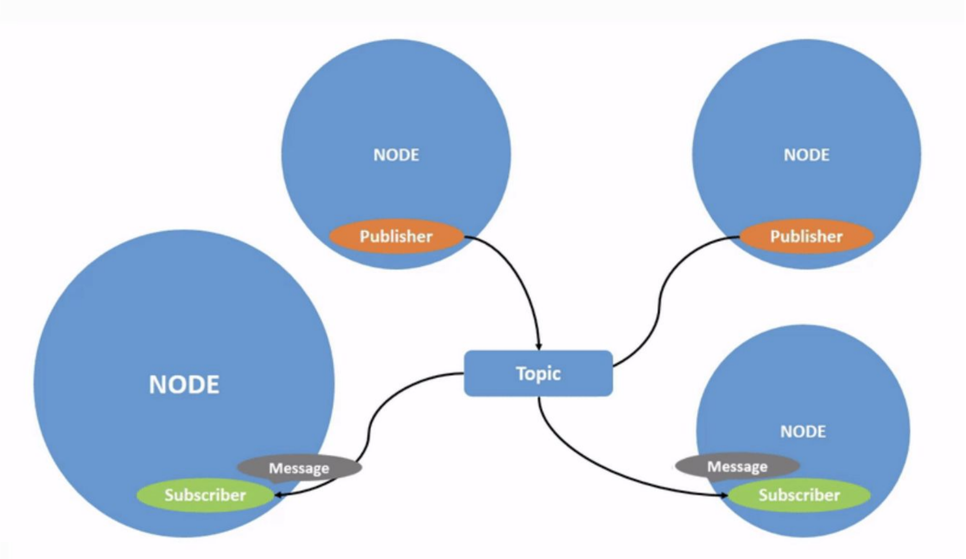
- **ROS (Robot Operating System)** is a set of tools and code that helps you build and control robots more easily.
- It lets different parts of a robot (like cameras, motors, or sensors) talk to each other.
- Each part runs separately, but ROS helps them work together like a team.
- People use ROS because it saves time, has many ready-to-use packages, and a big community for support.

Please ensure that the ROS2 installation is completed in the prelab.

ROS2 Node and Topic Overview

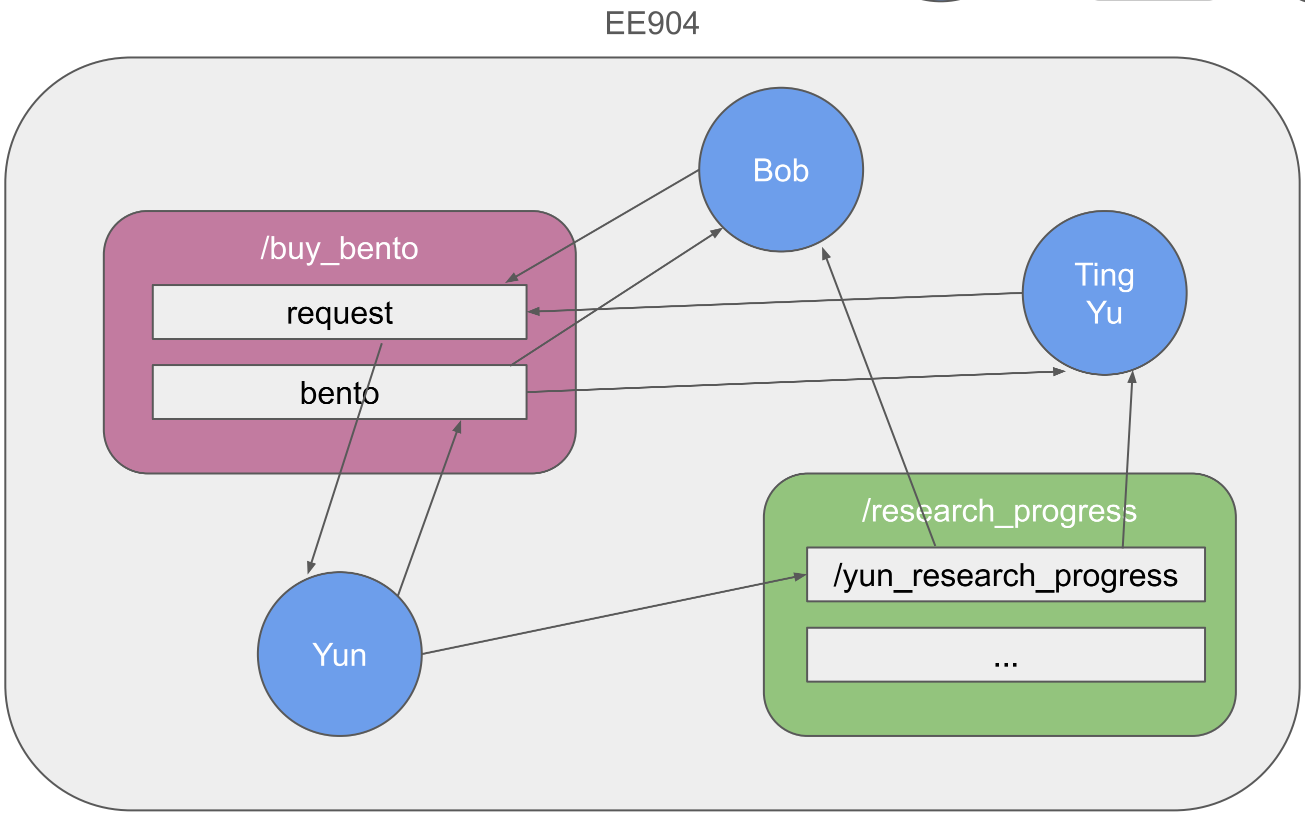
- Nodes perform specific tasks and communicate using topics, services, or actions.
- Topics and Services allow flexible data exchange between multiple publishers and subscribers.



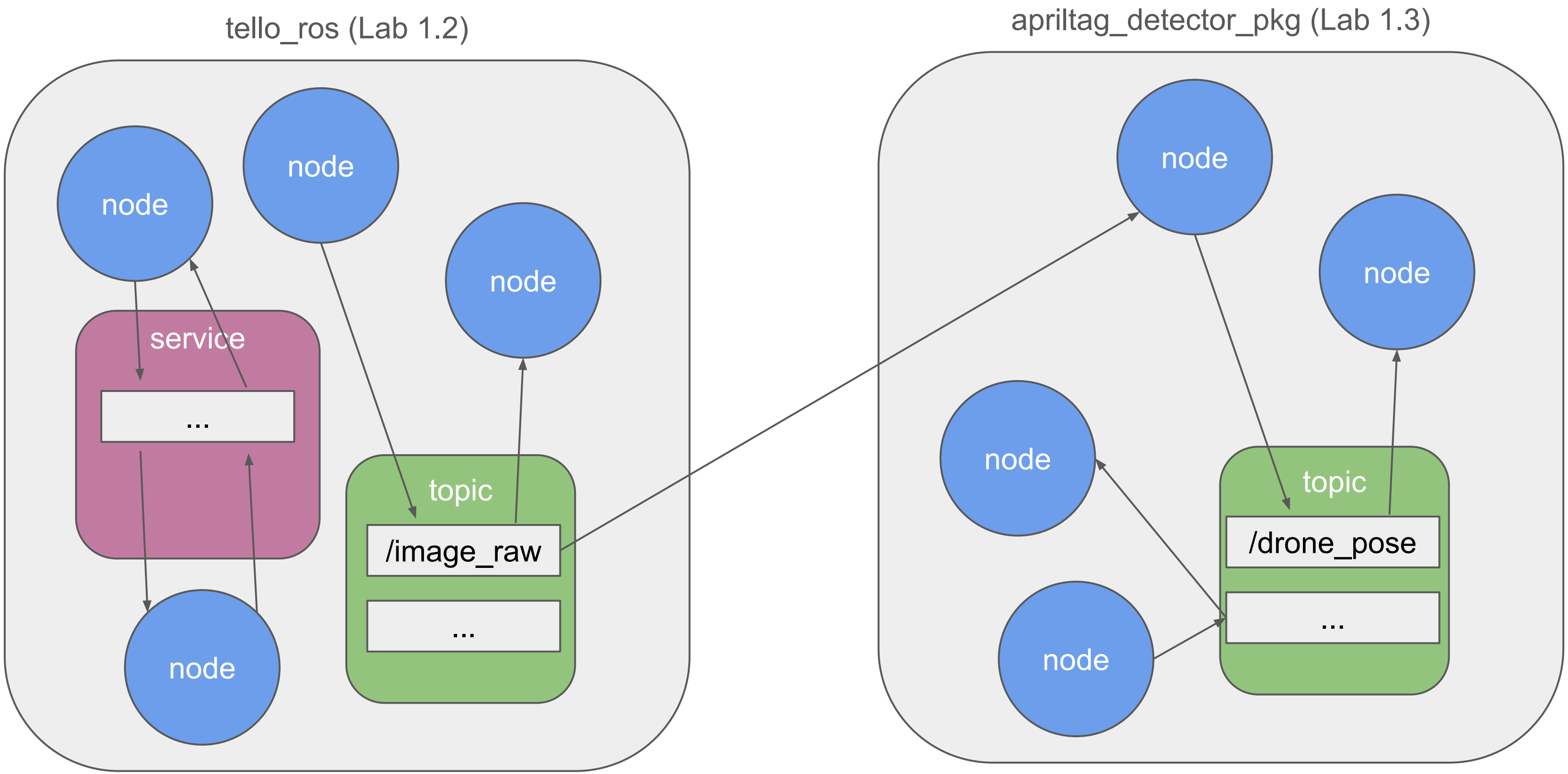


https://docs.ros.org/en/foxy/Tutorials/Beginner-CLI-Tools/Understanding-ROS2-Topics/Understanding-ROS2-Topics.html
https://docs.ros.org/en/rolling/Tutorials/Beginner-CLI-Tools/Understanding-ROS2-Nodes/Understanding-ROS2-Nodes.html

What is service? What is topic?



Example: Lab 1.2 & 1.3



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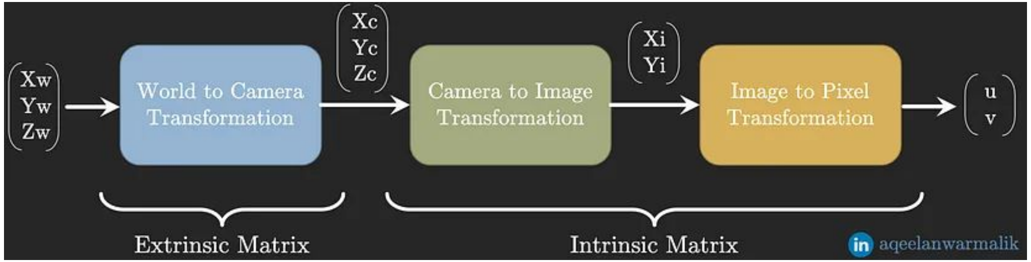
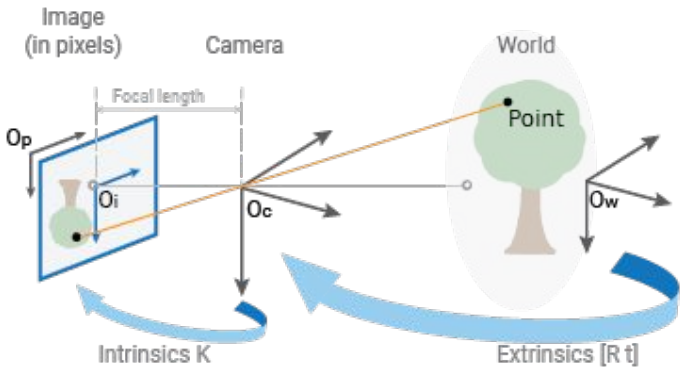
Coordinate Systems

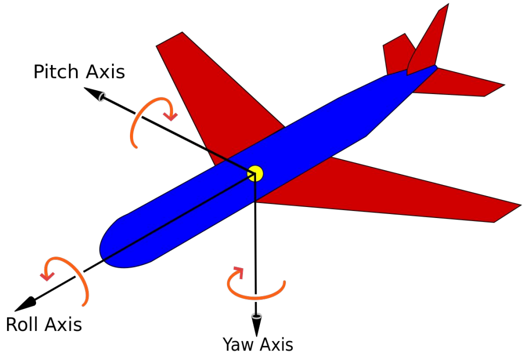
- Extrinsic: parameters of a camera depend on location and orientation (Pose)
  - World (3D) → Camera coordinate system (3D)
- Intrinsic: parameters of a camera depend on how it captures the images, such as focal length, aperture, field-of-view, resolution
  - Camera (3D) → Image (2D) → Pixel coordinate system (2D)



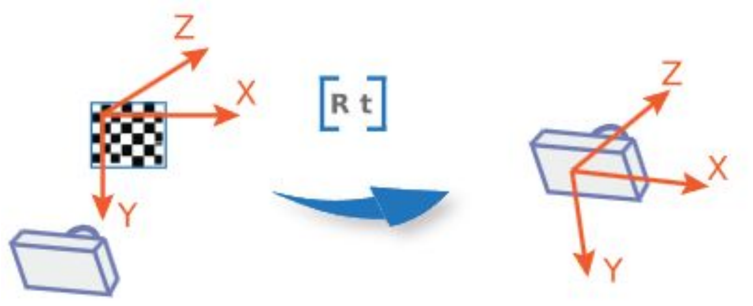


World (3D) → Pixel coordinate system (2D)

Extrinsic Matrix

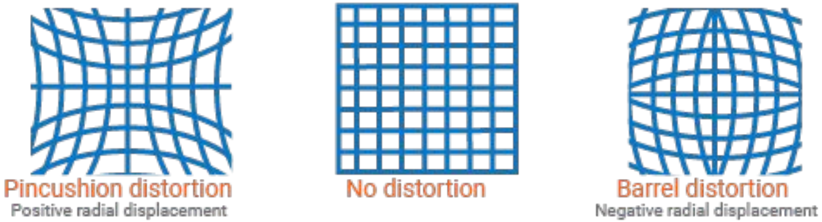


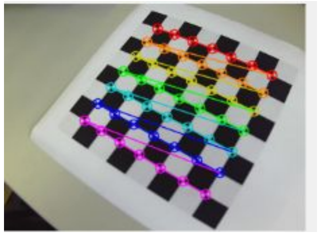
- World (3D) → Camera coordinate system (3D)
- Consist of a rotation matrix **R** and a translation matrix **t**.
- Pose estimation



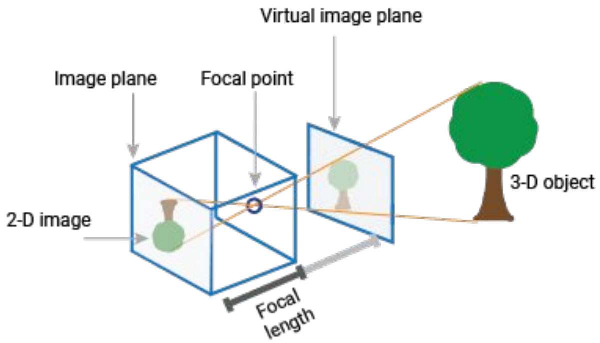
$$[R \mid t] = \left[\begin{array}{ccc|c} r_{1,1} & r_{1,2} & r_{1,3} & t_1 \\ r_{2,1} & r_{2,2} & r_{2,3} & t_2 \\ r_{3,1} & r_{3,2} & r_{3,3} & t_3 \end{array}\right]$$

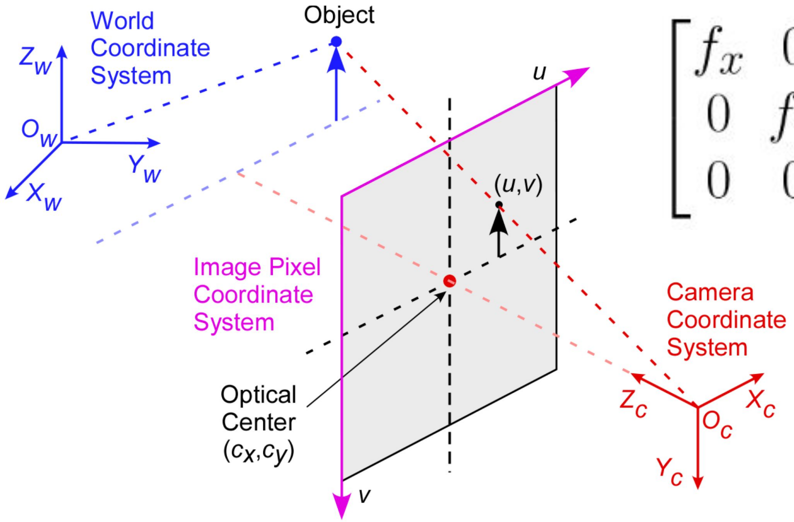
Intrinsic Matrix





- Camera (3D) → Image (2D) → Pixel coordinate system (2D)
- Pinhole camera model
- Distortion





$$\begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

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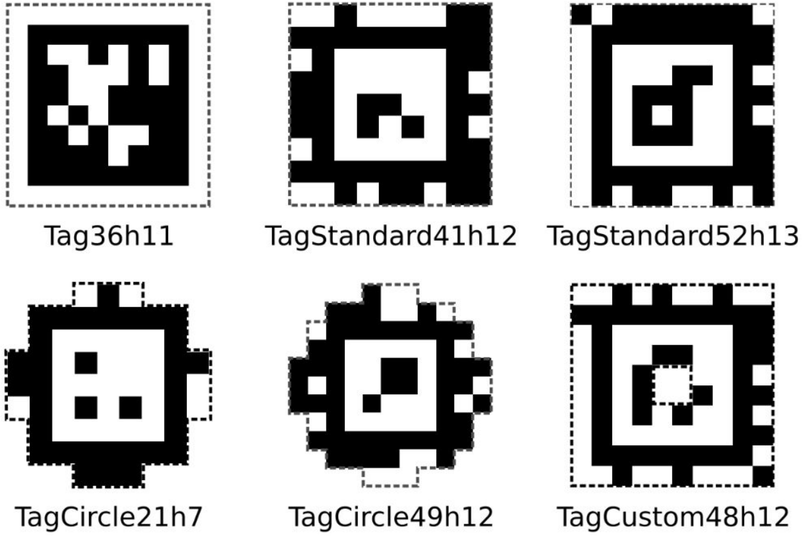
AprilTag

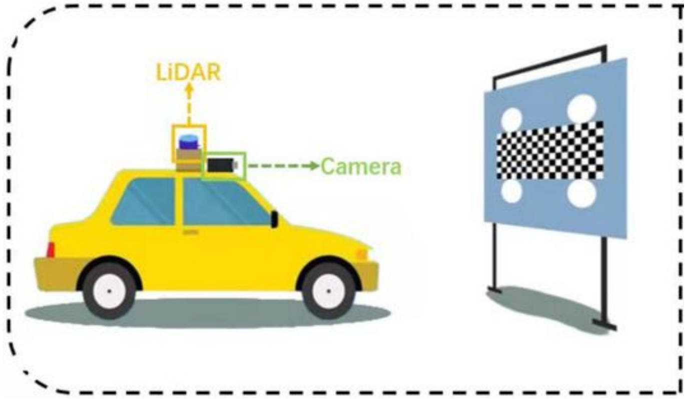
- Two-dimensional bar code, similar to QR Codes.
- Smaller data payloads, while still being detectable at longer distances.
- Can compute 3D pose (position, orientation), and tags ID relative to camera.

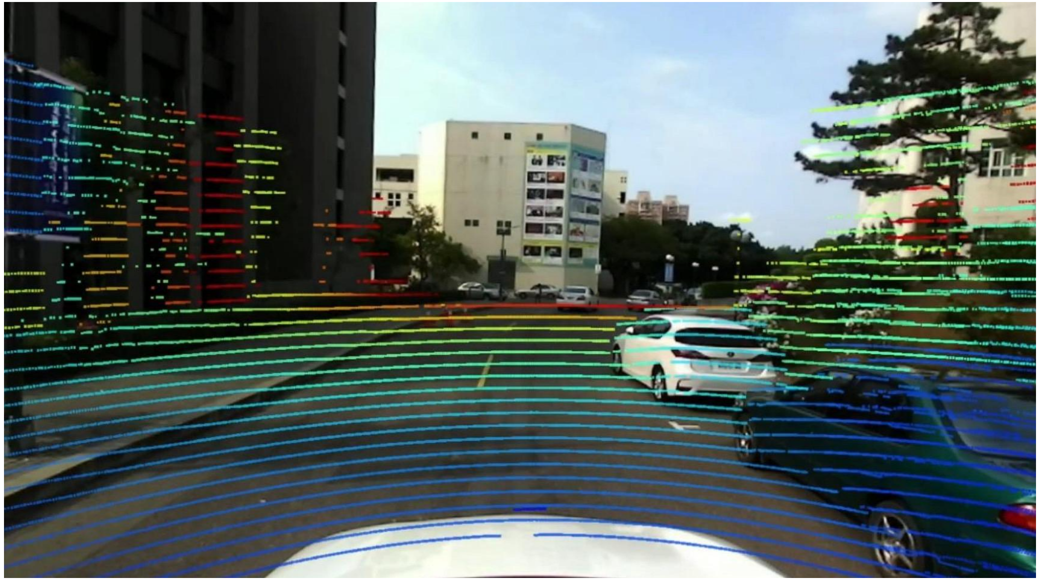


extrinsic

Calibration application

Intrinsic, Extrinsic, Temporal





[Hella Gutmann - 360° calibration for Advanced Driver Assist Systems (ADAS) (youtube.com)]

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Lab

Lab

1.1 Get camera’s intrinsic matrix and distortion coefficient.

1.2 Run Tello driver to see drone streaming.

1.3 Pose estimation using single AprilTag.

Lab 1.1 - Find camera intrinsic matrix

Download “camera_calibration.py” and “take_photo_flying.py” from here:

https://drive.google.com/drive/folders/14ky1Woz_MrXBU_clXLOt1t04xkMtqGvb?usp=drive_link

Take photos with “take_photo_flying.py”, you can just hold the drone by hand, or fly the drone if you want.

Put the photos in a folder.

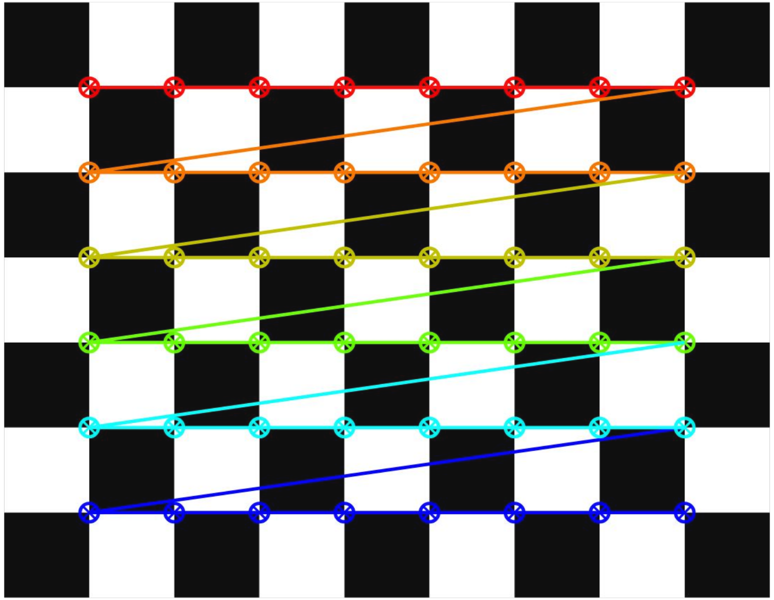
Measure the length of a square.

Fill in the blanks in “camera_calibration.py” and calculate the parameters.

Lab 1.1 - Find camera intrinsic matrix

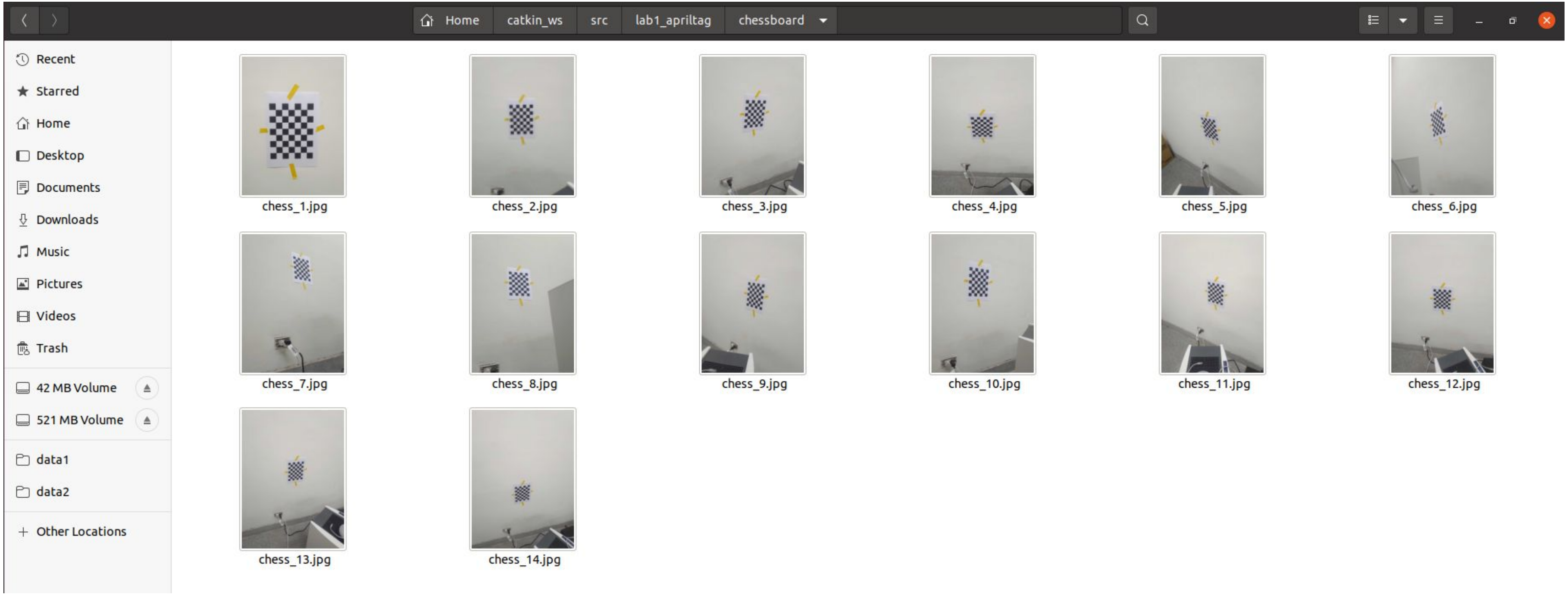
Capture multiple images of a chessboard using the camera and save them in a folder.

Measure the length of a square. (2.2 cm? you can measure by yourself)



Lab 1.1 - Find camera intrinsic matrix

Capture multiple images of a chessboard using the camera and save them in a folder.



Lab 1.1 - Find camera intrinsic matrix

Open camera_calibration.py and modify the path to the folder containing the chessboard images.

```
# Load images
images_folder = ???
images_list = os.listdir(images_folder)
```

Lab 1.1 - Find camera intrinsic matrix

Finished the code here, so it can show the value of fx, fy, cx, cy.

```python
# Print the camera matrix
print(f"Objective function value: {ret}\n")
print(f"Distorition coefficient: {dist}\n")
print("Camera Matrix:")
print(mtx)

fx = mtx[?, ?]
fy = mtx[?, ?]
cx = mtx[?, ?]
cy = mtx[?, ?]

print(f"\nfx: {fx}, fy: {fy}, cx: {cx}, cy: {cy}")
```

Lab 1.1 - Find camera intrinsic matrix

Open the terminal and type "python camera_calibration.py" Then the program will start executing and computing the intrinsic matrix and distortion coefficients.

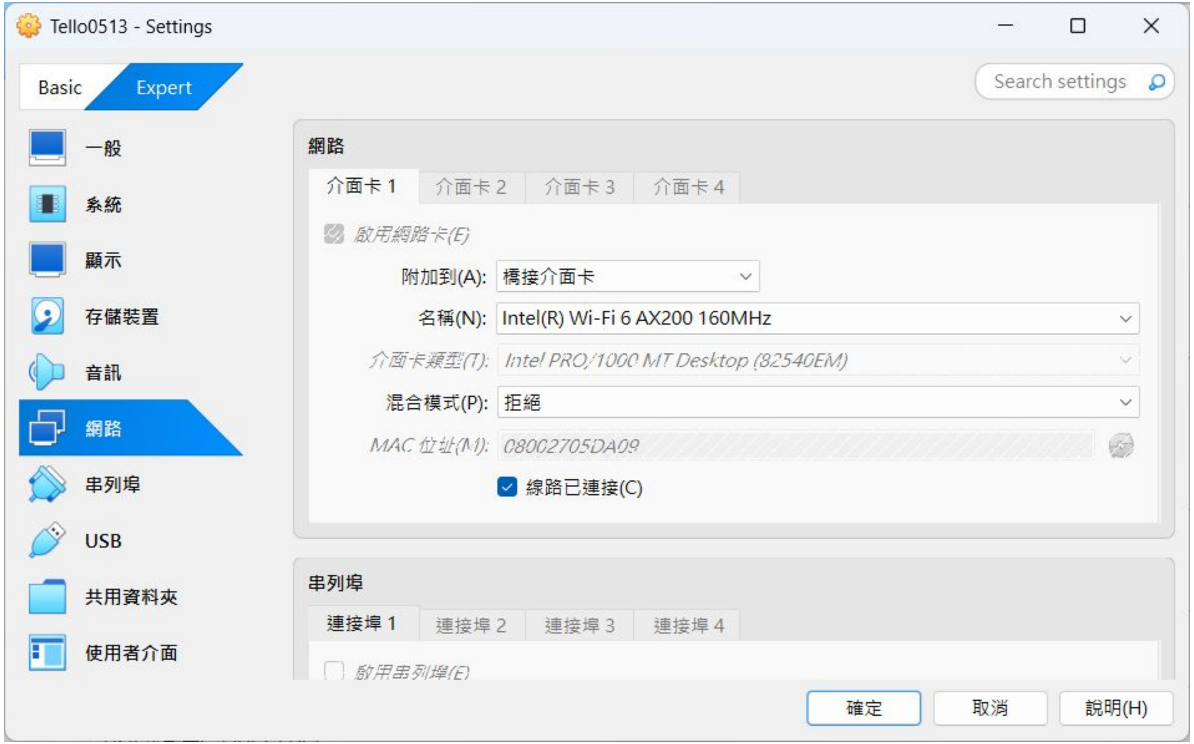
```
~/catkin_ws/src/lab1_apriltag/src ❯ python camera_calibration.py
Objective function value: 0.7488936896790611

Distorition coefficient: [[ 0.04884705  0.08326766  0.00990691 -0.00287781  0.51442997]]

Camera Matrix:
[[3.13524341e+03 0.00000000e+00 1.48682923e+03]
 [0.00000000e+00 3.13972523e+03 2.06891569e+03]
 [0.00000000e+00 0.00000000e+00 1.00000000e+00]]

fx: 3135.243406828593, fy: 3139.7252280414996, cx: 1486.8292332587046, cy: 2068.915688921479
```

Record the values of fx, fy, cx, cy, and distortion coefficient. These values will be used in the next program.

Lab 1.2 - Run Tello driver to see drone streaming

Set the network configuration to “橋接介面卡” on your VirtualBox.

It you haven’t install, refer to this prelab.



Lab 1.2 - Run Tello driver to see drone streaming

Do the "Installation" section of this repository:

[clydemcqueen/tello_ros: C++ ROS2 driver for DJI Tello drones [requires Foxy and Gazebo Classic -- both EOL]]

1. Set up your Linux environment

Set up a Ubuntu 20.04 box or VM.

Also install asio:

```
sudo apt install libasio-dev
```

2. Set up your ROS environment

Install ROS2 Foxy with the `ros-foxy-desktop` option.

If you install binaries, be sure to also install the development tools and ROS tools from the source installation instructions.

Install these additional packages:

```
sudo apt install ros-foxy-cv-bridge ros-foxy-camera-calibration-parsers
```

3. Install `tello_ros`

Download, compile and install `tello_ros`:

```
mkdir -p ~/tello_ros_ws/src
cd ~/tello_ros_ws/src
git clone https://github.com/clydemcqueen/tello_ros.git
git clone https://github.com/ptrmu/ros2_shared.git
cd ..
source /opt/ros/foxy/setup.bash
# If you didn't intall Gazebo, skip tello_gazebo while building:
colcon build --event-handlers console_direct+ --packages-skip tello_gazebo
```

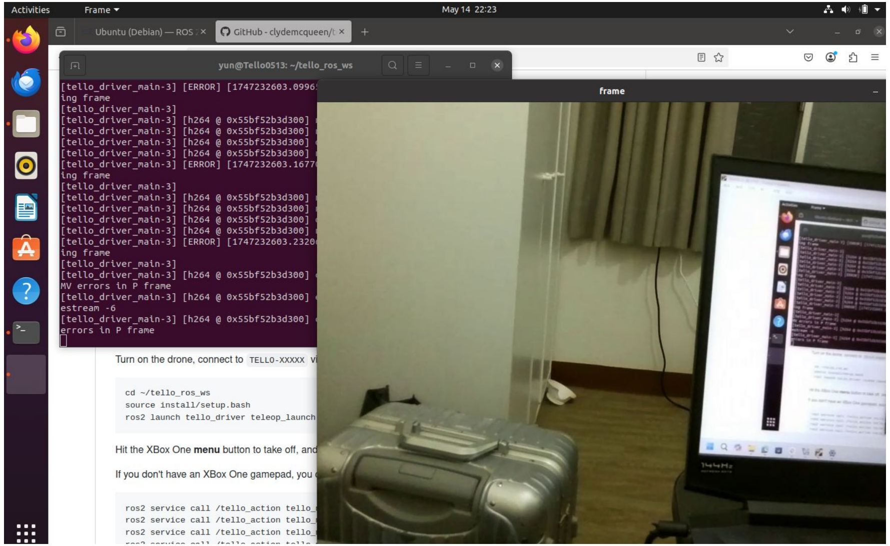
Lab 1.2 - Run Tello driver to see drone streaming

Turn on the drone, connect to its wifi, do the following commands:

cd ~/tello_ros_ws

source install/setup.bash

ros2 launch tello_driver teleop_launch.py



Lab 1.3 - Pose estimation using single AprilTag

Do the first step of 1.3 from this guide:

https://hackmd.io/@L-In544OTxi8tkHC4JCwsg/SJ9h3MM-gg

Fill in the blanks in code.

```
# Add publisher
self.pose_pub = self.create_publisher(PoseStamped, '/drone_pose', 10)

# === Camera intrinsics === (You must adjust based on your Tello's camera)
self.fx = ???  # Focal length x
self.fy = ???  # Focal length y
self.cx = ???  # Principal point x (image center)
self.cy = ???  # Principal point y

# Tag size in meters
self.tag_size = ???

self.get_logger().info("Pose publisher Initialized.")
```

Then continue with the guide.