Cyber-physical systems programming

Visual Inertial Odometry for a Crazyflie drone

Group components:

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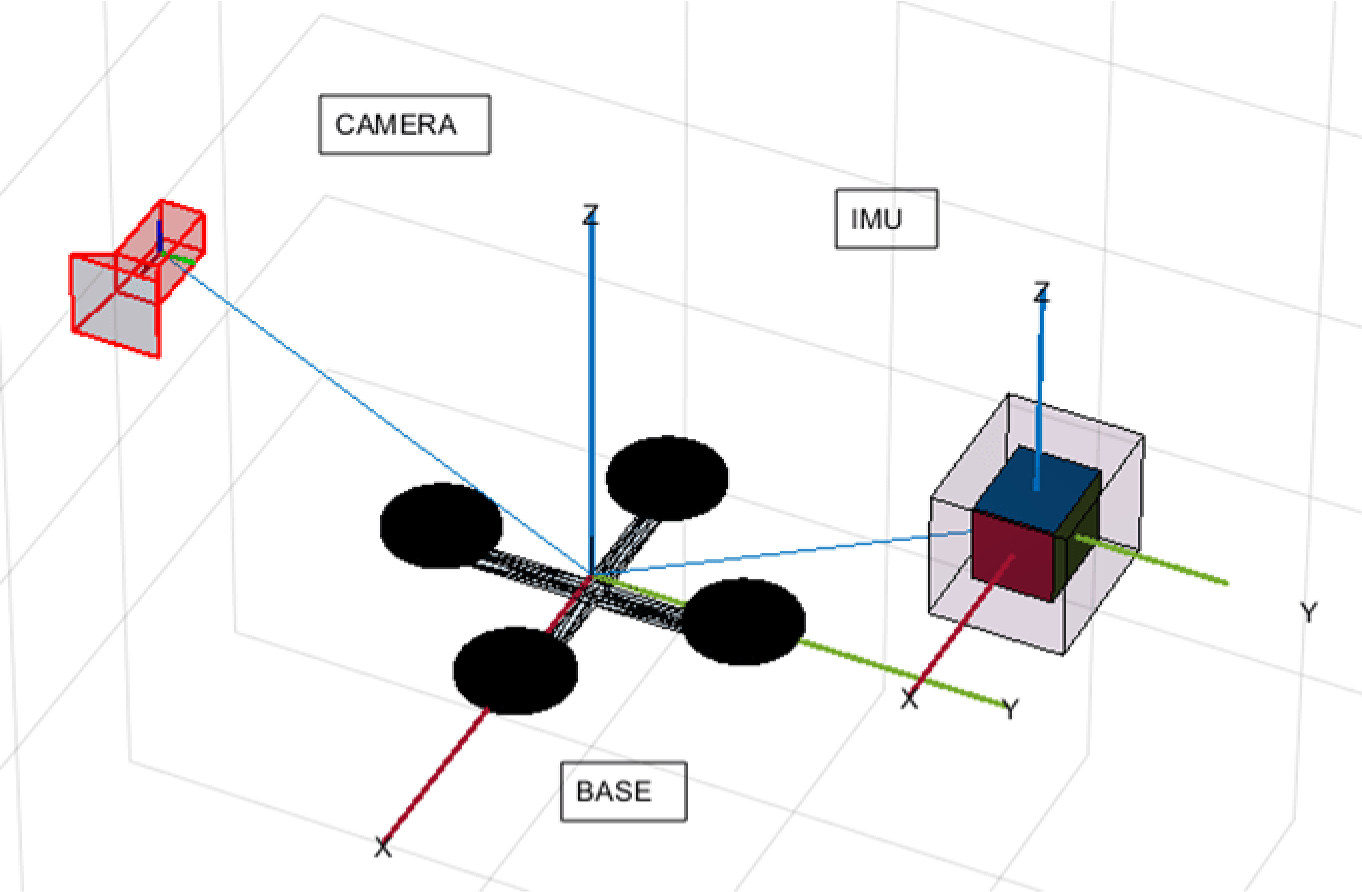
Visual Inertial Odometry Algorithm

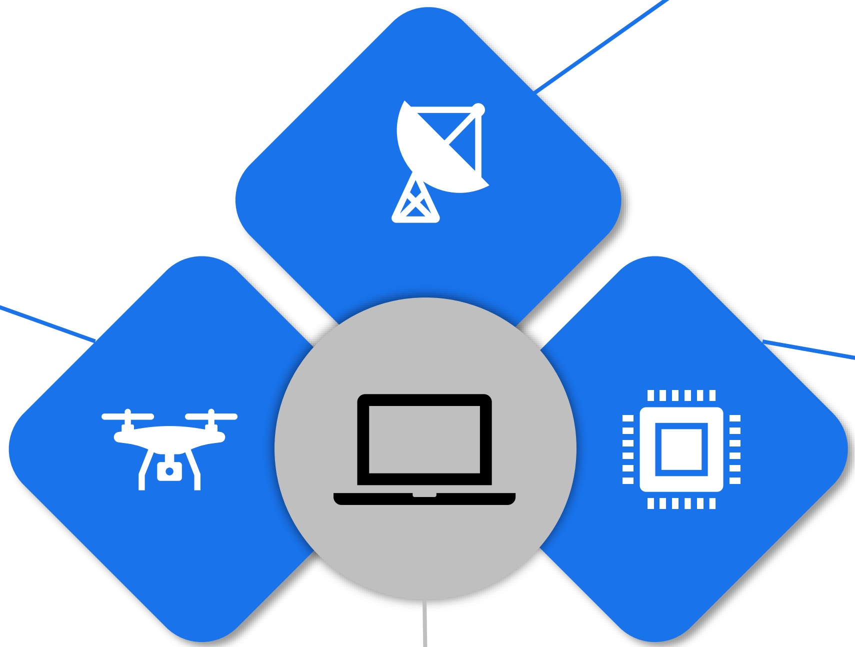
- The Visual Inertia Odometry (VIO) is a localization technique for the estimation in real time of the position and orientation of an autonomous device in an environment.
- It combines visual information acquired throughout cameras and inertial data provided by IMU sensors.



Hardware components

Crazyradio 2.0:

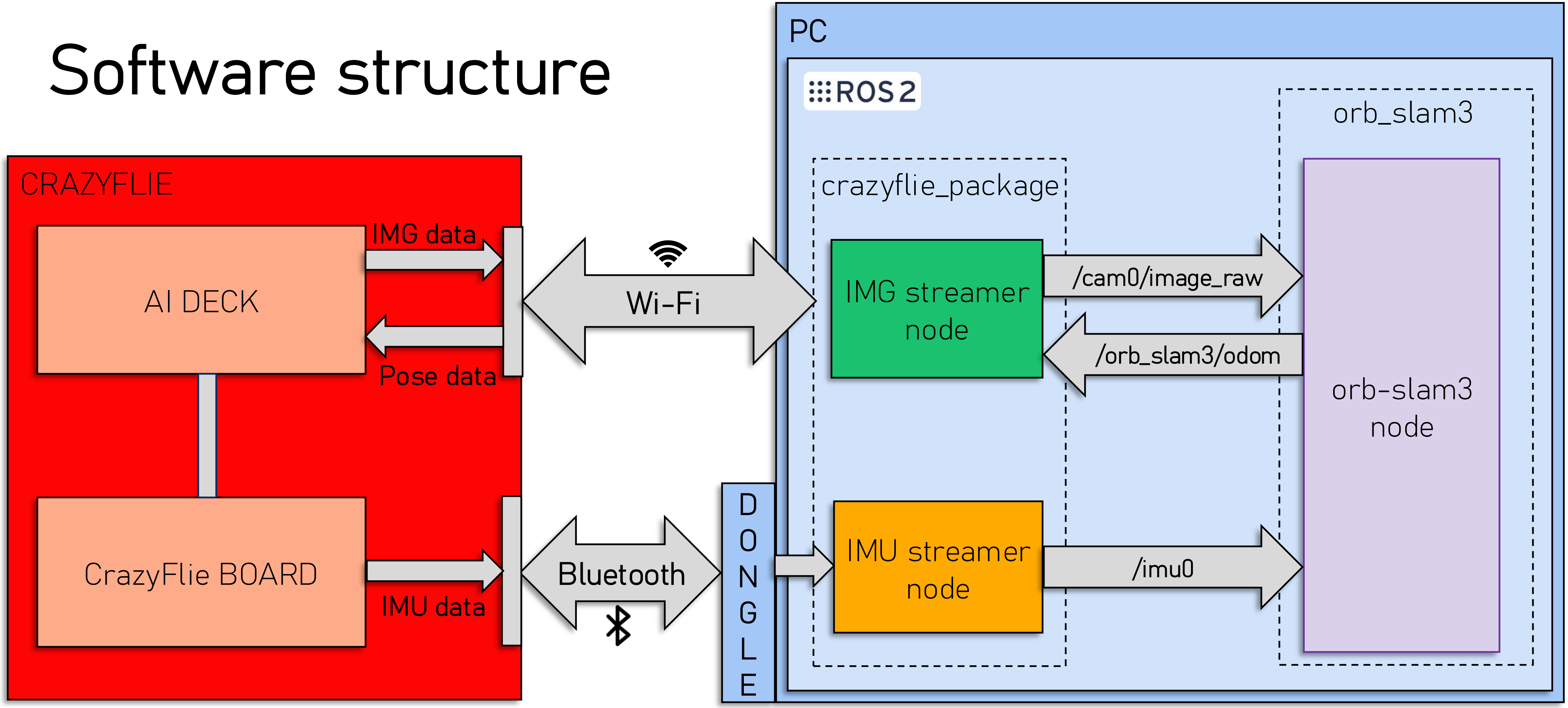
Crazyflie 2.1 drone:



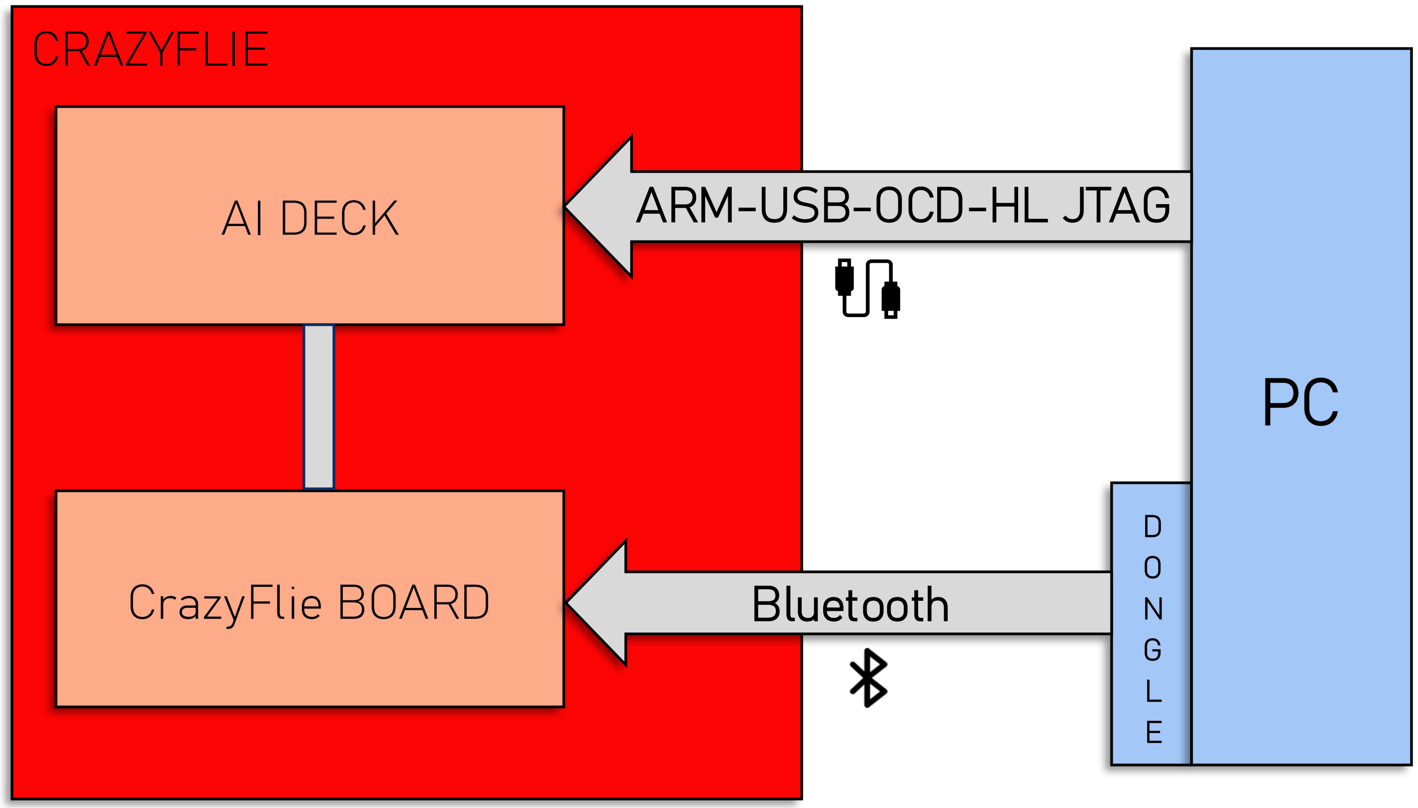
AI-deck:

PC for computations

Software structure



Section 1: Drone Setup



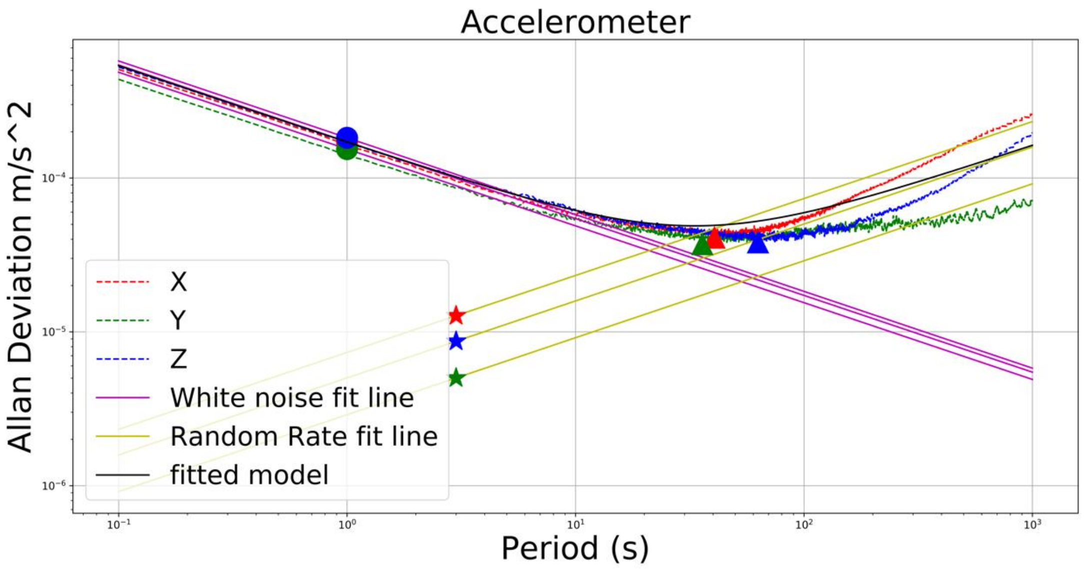
Firmware Setup

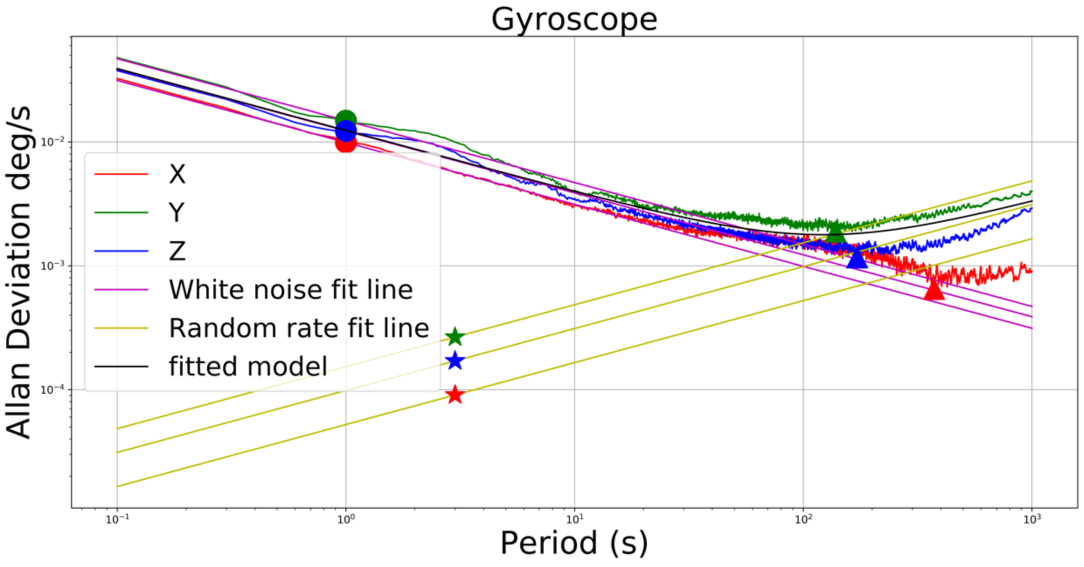
BUILD AND FLASH OF THE GAP8 BOOTLOADER WITH AN **OLIMEX ARM-USB-OCD-HL JTAG**

FLASHING OF THE FIRMWARE AND THE DEVELOPED APPLICATION FOR THE GAP8 VIA THE CRAZYRADIO DONGLE

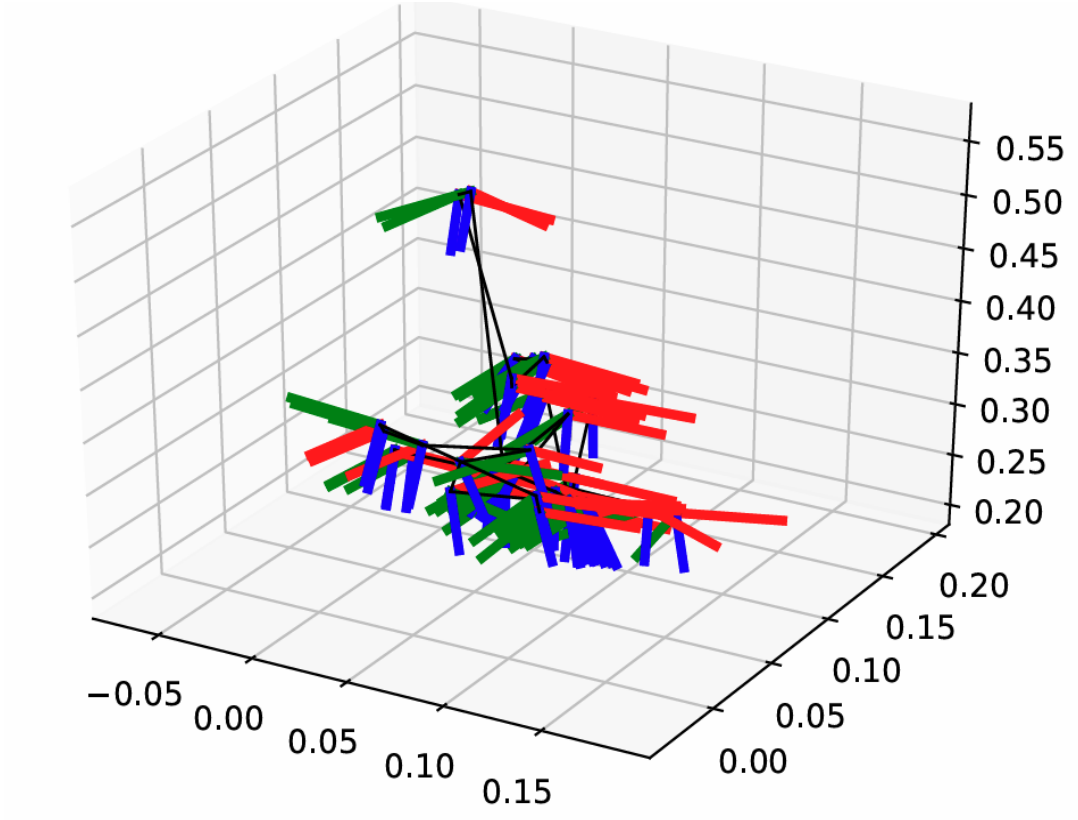
IMU Calibration

Sensor	Noise Density	Random Walk
Accelerometer	$0.000176 \frac{m}{\sqrt{s^3}}$	$3.4328 \times 10^{-5} \frac{m}{\sqrt{s^5}}$
Gyroscope	$0.000260 \frac{rad}{\sqrt{s}}$	$2.0043 \times 10^{-5} \frac{rad}{\sqrt{s^3}}$



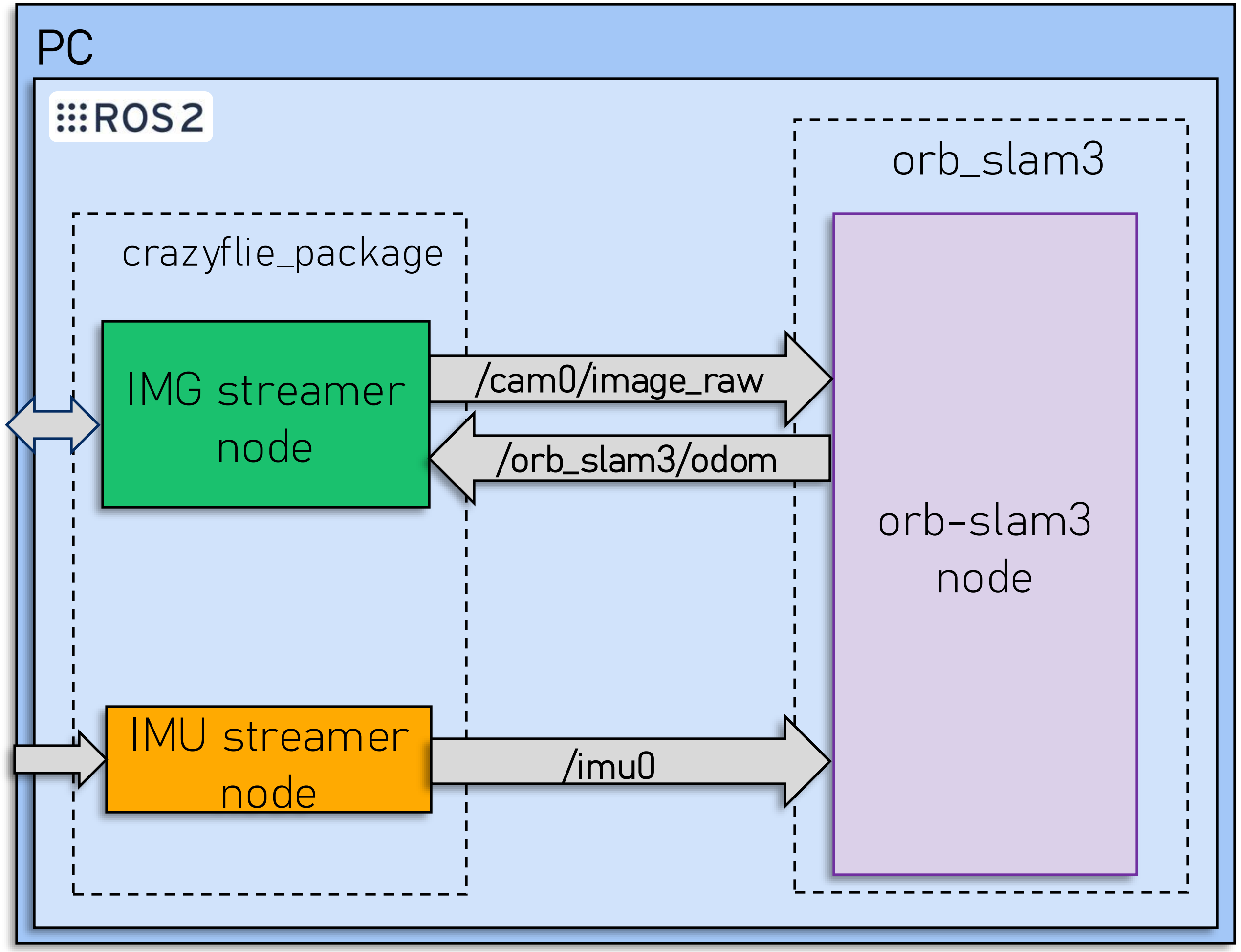


IMU + Camera Calibration



Parameter	Value
Focal length	$[182.040108, 181.960582]$
Principal point	$[161.919551, 153.772955]$
Radial distortion coefficients	$[-0.072991,\ -0.005429]$
Tangential distortion coefficients	$[-0.000866,\ 0.000639]$
Rotation matrix	$\begin{bmatrix} -0.00658 & -0.99998 & -0.00051 \\ -0.22460 & 0.00198 & -0.974445 \\ 0.97443 & -0.00629 & -0.22461 \end{bmatrix}$
Translation vector	$[-0.0292 \quad 1.1811 \quad 0.6743]^T$

Section 2: ROS2 environment



IMU STREAMER NODE

01 The *imu_streamer* node is initiated and it connects to the drone via the Crazyradio dongle

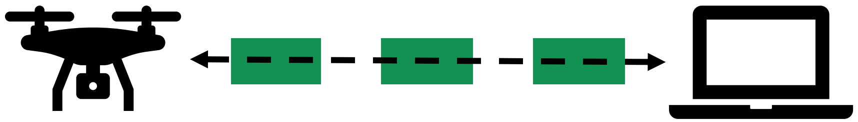
02 The node starts logging IMU data from the drone:
- *Accelerometer data*
- *Gyroscope data*

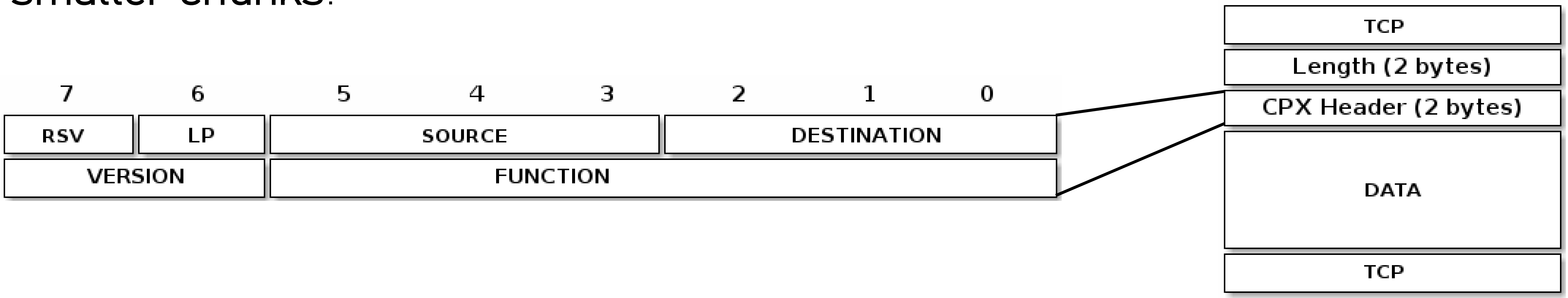
03 A ROS2 message of type *Imu()* is instantiated and filled with the logged values

04 The Imu message is then published in the */imu0* topic

WI-FI COMMUNICATION PROTOCOL

The image communication is performed using the **TCP protocol**, with data packets structured according to the custom convention CPX. Due to the images size, they are split into several **smaller chunks**.





IMG STREAMER NODE

01 The *img_streamer* node is initiated, and it connects to the AI-deck via WIFI

02 The node reconstructs the images reshaping it into a 244 x 324 grayscale image

03 A ROS2 message of type *Image()* is filled with the image (with a bridge)

04 The message is published on the topic */cam0/image_raw* with the associated TimeStamp

05 Receives estimated pose on the topic */orb_slam3/odom* and sends it back to the drone via WiFi

ORB_SLAM3 NODE

orb_slam3

orb_slam3.cpp

- Subscribes to image and camera topics.
- Manages those data through an instance of the DataGrabber class.
- Sends back to img_streamer node the estimated pose.

data_grabber library

- Receives image and IMU messages and queues them internally using buffers.
- Feed synchronized data to the ORB-SLAM3 tracking system.
- Receives estimated pose.

VIO algorithm

ORB_SLAM3 VIO ALGORITHM

ORB-SLAM3 is a real-time SLAM system that supports **visual, visual-inertial, and multi-map SLAM** using **monocular, stereo, and RGB-D cameras**, compatible with both **pin-hole and fisheye lens models**.

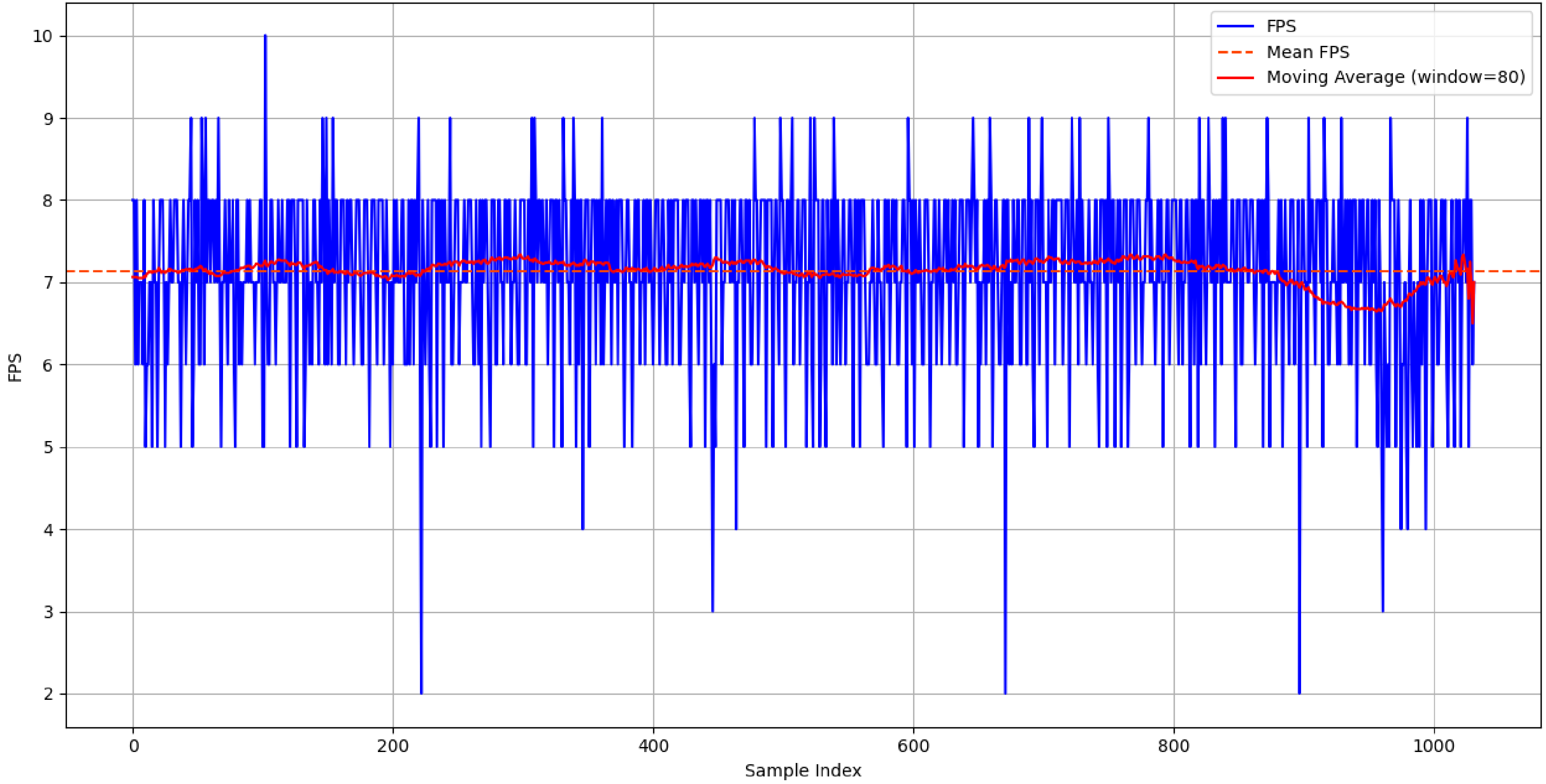
It extracts ORB features from the image while integrating IMU data, then defines the MAP-based optimization problem,

Optimization solved through tightly-coupled bundle adjustment, minimizes visual reprojection and inertial errors.

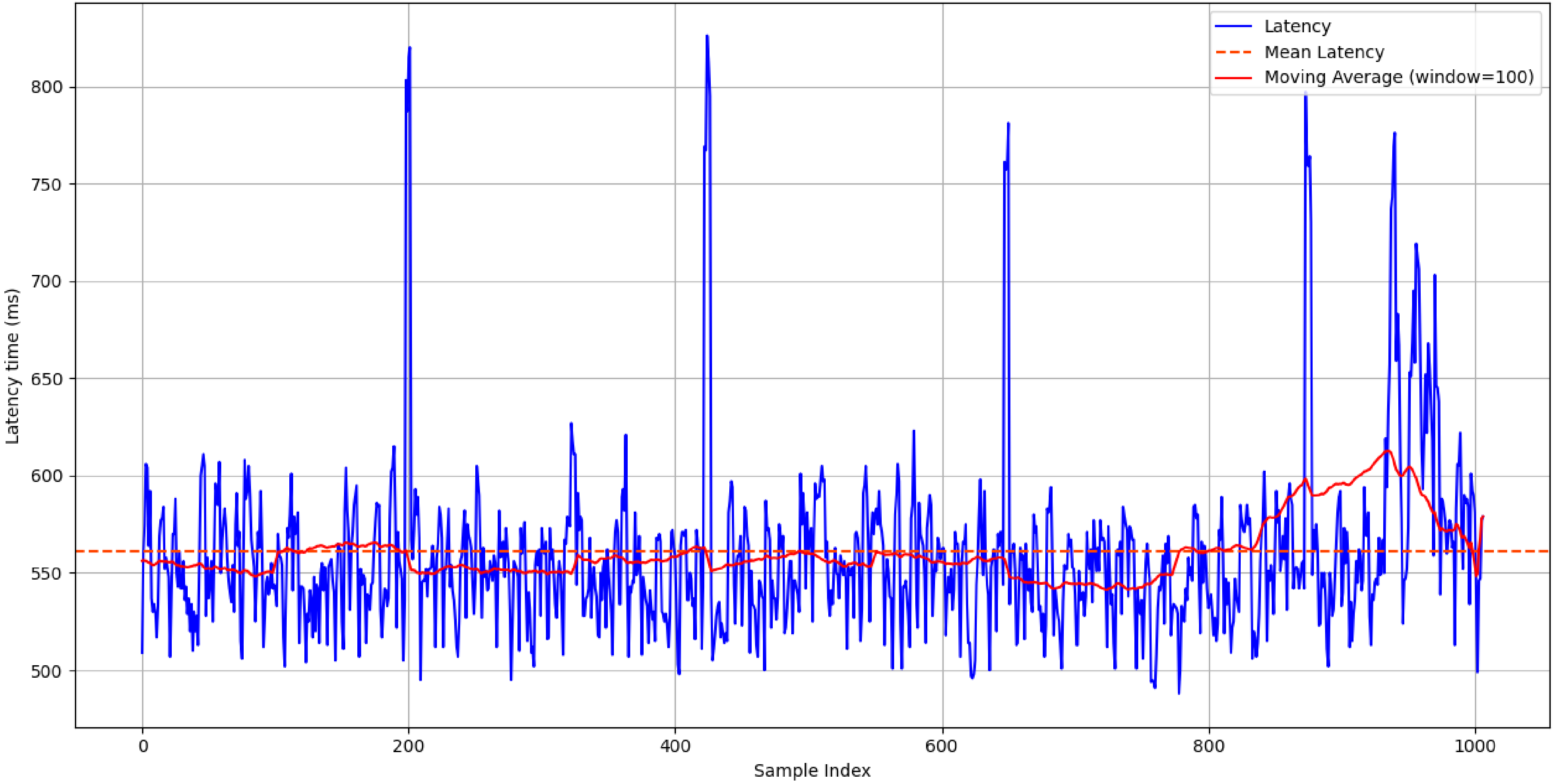
Performance enhanced by DBoW2-based place recognition for loop closure and drift correction.

Section 3: Results

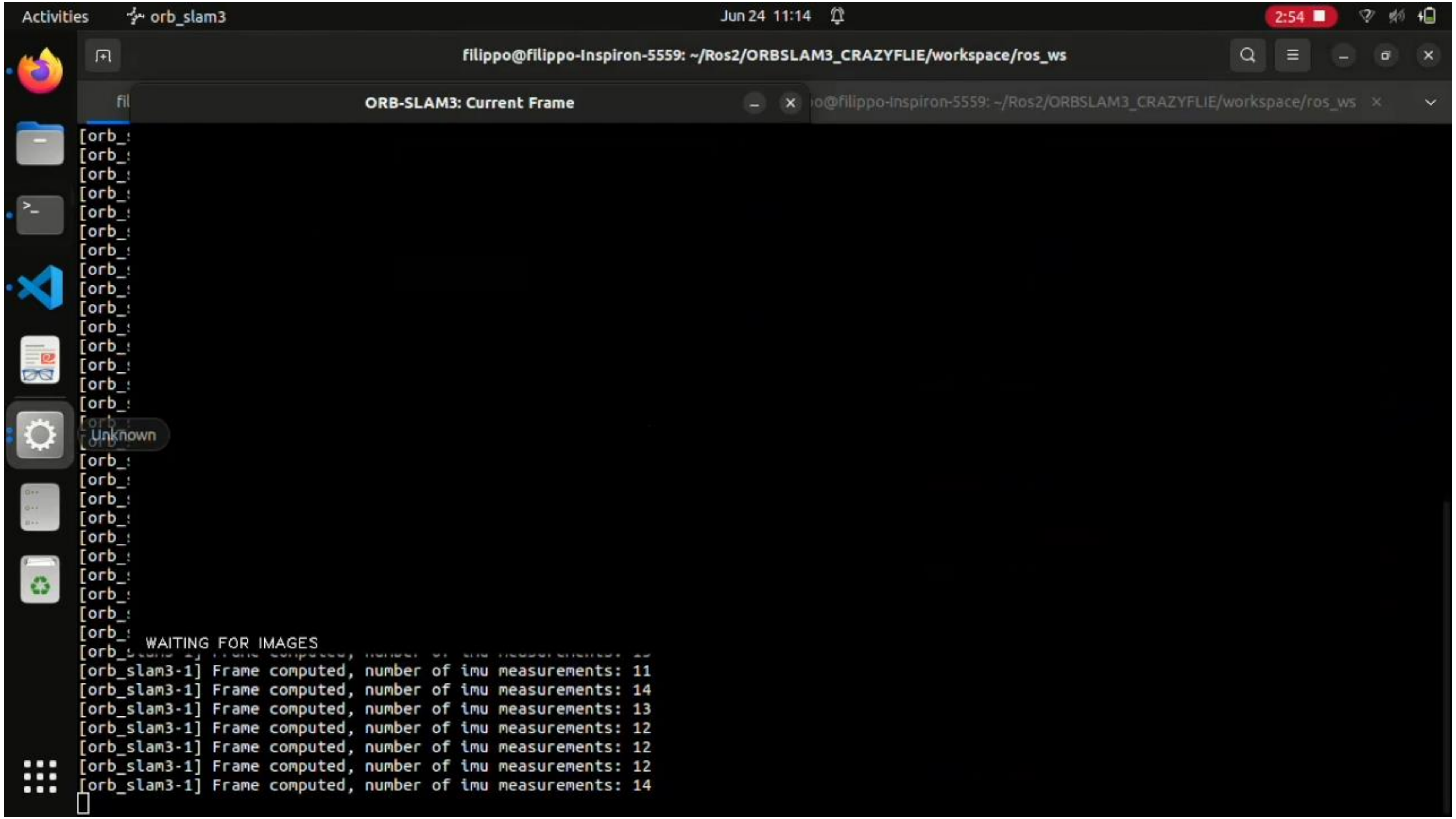
Performances: FPS



Performances: Latency



Video


Activities
orb_slam3
Jun 24 11:14
2:54
filippo@filippo-Inspiron-5559: ~/Ros2/ORBSLAM3_CRAZYFLIE/workspace/ros_ws
ORB-SLAM3: Current Frame
Unknown
WAITING FOR IMAGES
[orb_slam3-1] Frame computed, number of imu measurements: 11
[orb_slam3-1] Frame computed, number of imu measurements: 14
[orb_slam3-1] Frame computed, number of imu measurements: 13
[orb_slam3-1] Frame computed, number of imu measurements: 12
[orb_slam3-1] Frame computed, number of imu measurements: 12
[orb_slam3-1] Frame computed, number of imu measurements: 12
[orb_slam3-1] Frame computed, number of imu measurements: 14

Conclusions

Main goal achieved: Successful integration of Crazyflie, AI-deck, and ROS2 using dual communication (Wi-Fi + Bluetooth) for the Visual Inertial Odometry.

Challenges addressed:

- Logging of data from both IMU and Camera;
- Integration of different frameworks (Orb Slam 3, ROS2, CF library, GAP8 programming);
- Performance improvement (i.e. FPS).

System limitations:

- Communication constraints;
- Poor camera resolution.

Ideas for performance improvements

Develop the application outside the ROS2 framework for increased performances.

Define a better strategy to use a single channel for the communication.

Improve the camera system (higher resolution, stereo or RGB-D cameras).

Future applications

TRACKING OF COMPLEX TRAJECTORIES

Validation of the control algorithm's precision through high-fidelity trajectory tracking.

AUTONOMOUS FLIGHT

Integration of the ROS2 Navigation Stack to enable fully autonomous missions.

COMPUTER VISION

Use camera for environment perception and obstacle avoidance through lightweight neural networks on embedded hardware.

MULTI-DRONE COOPERATION

Coordination of multiple Crazyflie units through shared ROS2 topics and synchronized control nodes.

THANKS FOR YOUR ATTENTION!