Monocular Visual Inertial Simultaneous Localization and Mapping for Detecting Obstacles through Point Clouds

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Introduction

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Introduction

- An autonomous vehicle should be aware of its environment to take the next decision.

- SLAM (Simultaneous Localization and Mapping) systems can localize and map the environment at the same time.

Introduction

- The objective of this special study is to generate real time point clouds and robot poses by executing a monocular visual inertial SLAM algorithm.

- The scope of the study is to build a visual inertial SLAM system that can provide point clouds and robot pose to other components in the perception/action pipeline of an autonomous robot.

Literature Review

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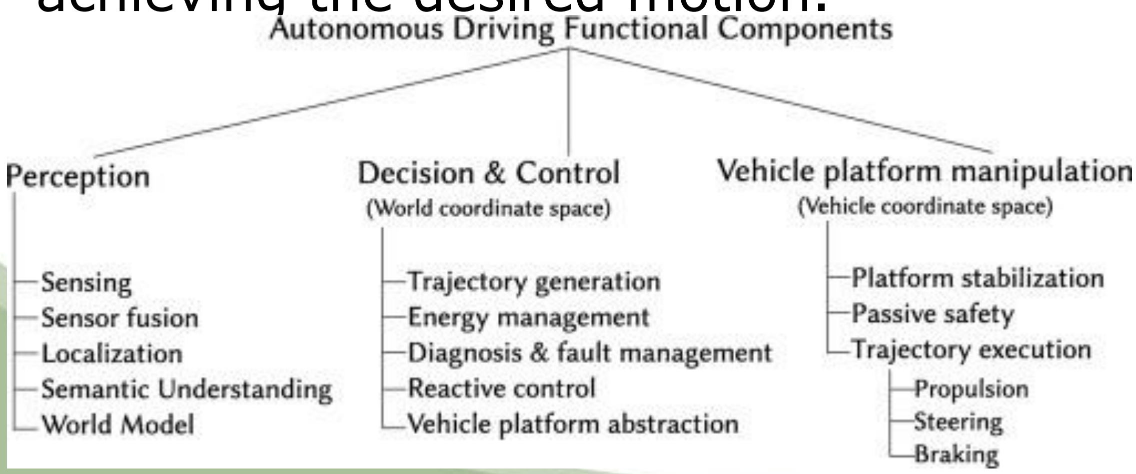
Software Architecture of Autonomous Driving Vehicles

- Perception of the environment in which the vehicle operates.
- Decision making and control of vehicle motion with respect to the external environment that is perceived.
- Vehicle platform manipulation, which deals with achieving the desired motion.



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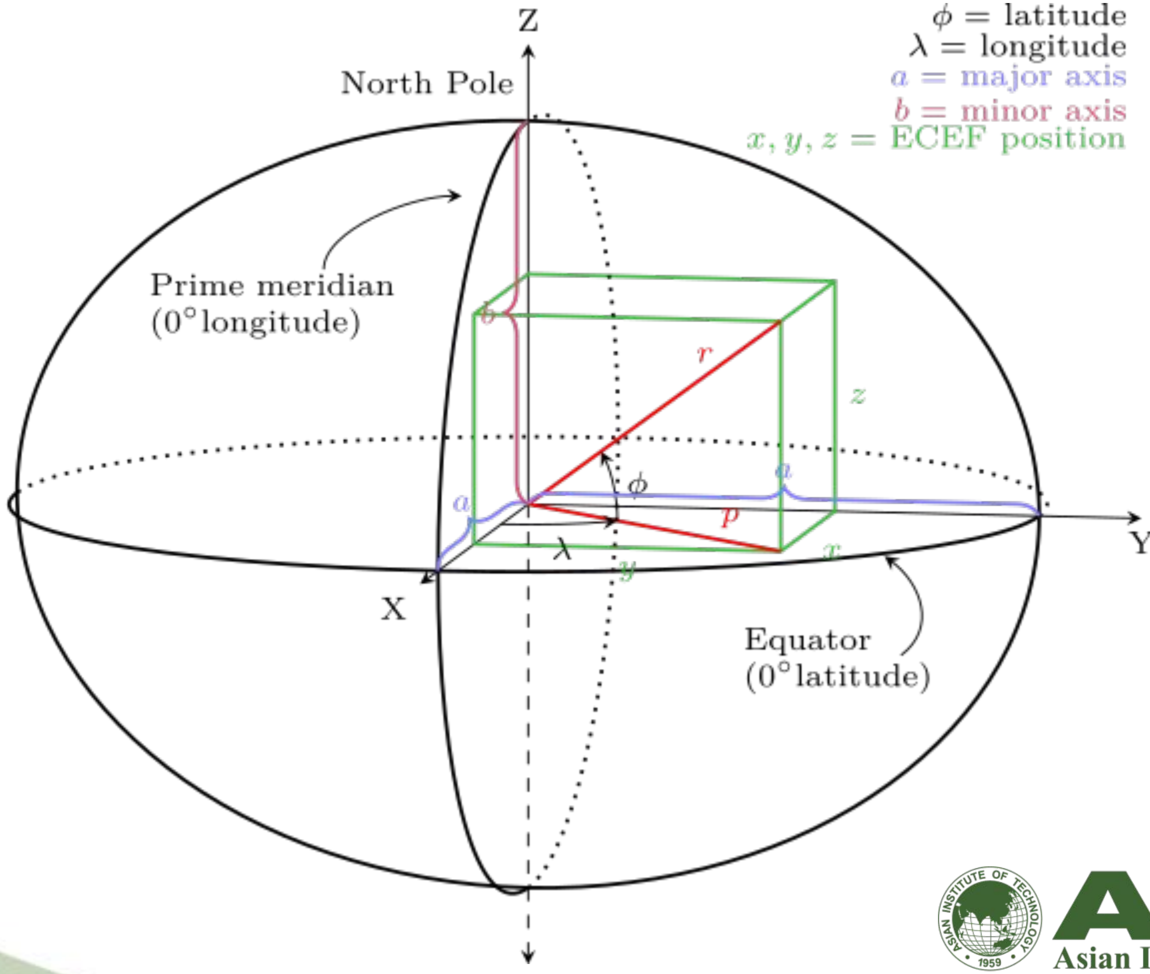
Coordinate Systems(Earth Centric, Earth Fixed)



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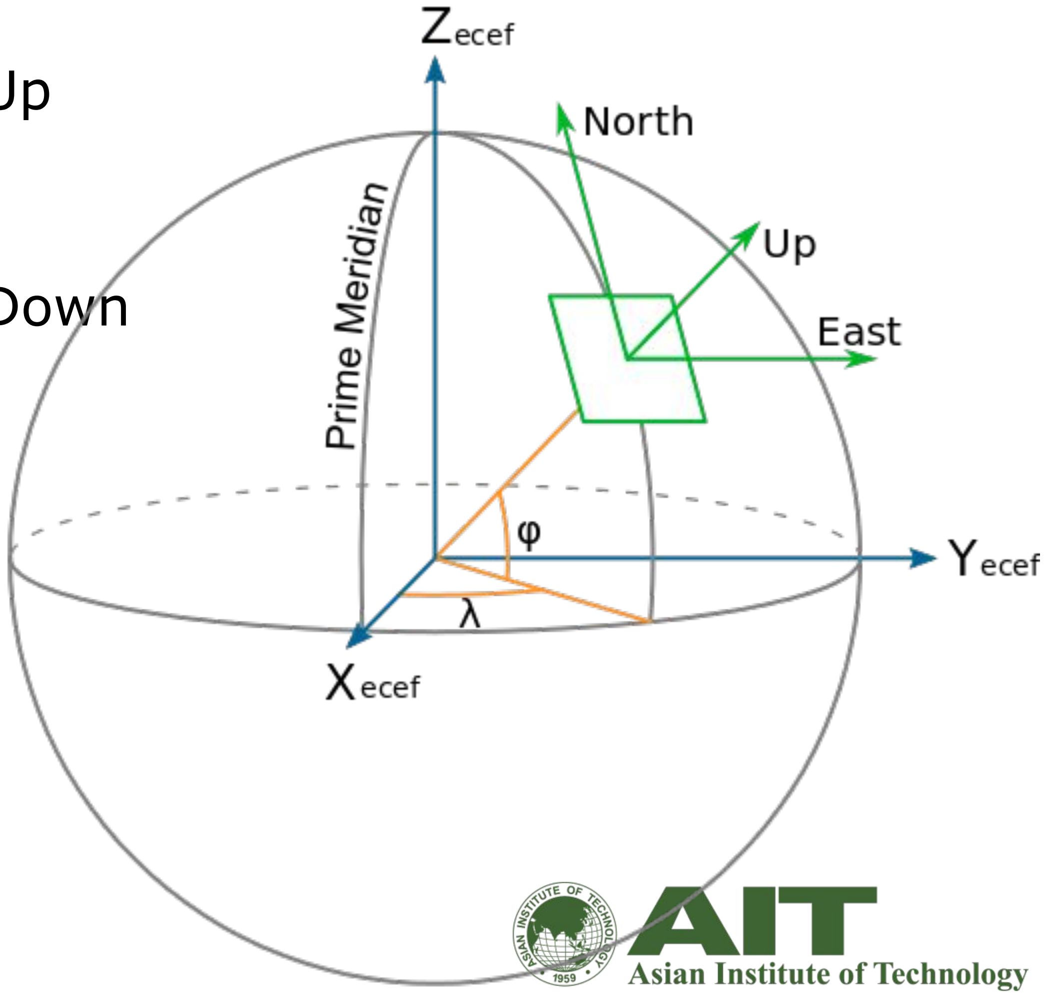
Coordinate Systems(Local Tangent Plane)

- X=East, Y=North, Z=Up (ENU).
- X=North, Y=East, Z=Down (NED)



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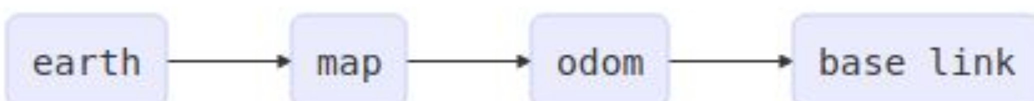
Coordinate Systems(PixHawk and ROS)

- PixHawk follows the NED convention.
- ROS follows the ENU convention.
- ROS has other reference frames
  - base_link is rigidly attached to the mobile robot base.
  - odom is a world fixed frame.
  - map is a world fixed frame. with Z axis pointing upwards.
  - earth is the origin on the ECEF frame



Simultaneous Localization and Mapping

- A method by which a mobile robot can build a map of an environment and at the same time use this map to infer its location.

- The trajectory of the platform and the location of all landmarks are estimated online without the need for any previous information of the location.

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Visual SLAM

- Images from one or more cameras are used for observation of the landmarks.
- Visual SLAM can be classified into feature based and direct methods.
- Feature based methods extract features from the input image and use those features as observations.
- Direct methods for vSLAM takes the whole image for tracking and mapping and produce dense point clouds.

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Visual SLAM

- Some of the important vSLAM algorithms are
  - Parallel Tracking and Mapping (PTAM)
  - ORB SLAM
  - ORB SLAM2

- Some of the direct vSLAM algorithms are
  - Dense Tracking and Mapping (DTAM)
  - Large-Scale Direct SLAM (LSD SLAM)

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Visual SLAM Modules

- Initialization
- Tracking
- Mapping
- Re-localization
- Global map optimization

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ORB SLAM

- Feature based vSLAM algorithm.

- Uses ORB feature detectors and the same features are used in mapping as well as tracking.

- It has three threads running in parallel for tracking, local mapping and loop closing.

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Visual Inertial ORB SLAM

- Extends upon ORB SLAM by integrating stream of IMU measurements which solves the scale ambiguity problem of monocular SLAM.

- In tracking, the IMU pose is estimated and the camera pose is predicted.

- In local mapping, the local window is retrieved by the transitory sequence of keyframes, while in ORB SLAM covisibility graph is used.

- In loop closing, the pose graph optimization is performed on 6 degrees of freedom instead of 7 degrees of freedom as scale is observed.

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Methodology

Hardware

- The Mobius Maxi action cam mounted on a rigid base.

- The PixHawk 2.4.8 flight controller with internal IMU and external GPS module is attached to the same rigid base.

- Both devices are connected through USB to a laptop with
  - i7 CPU
  - 16 GB of RAM
  - Ubuntu 16.04

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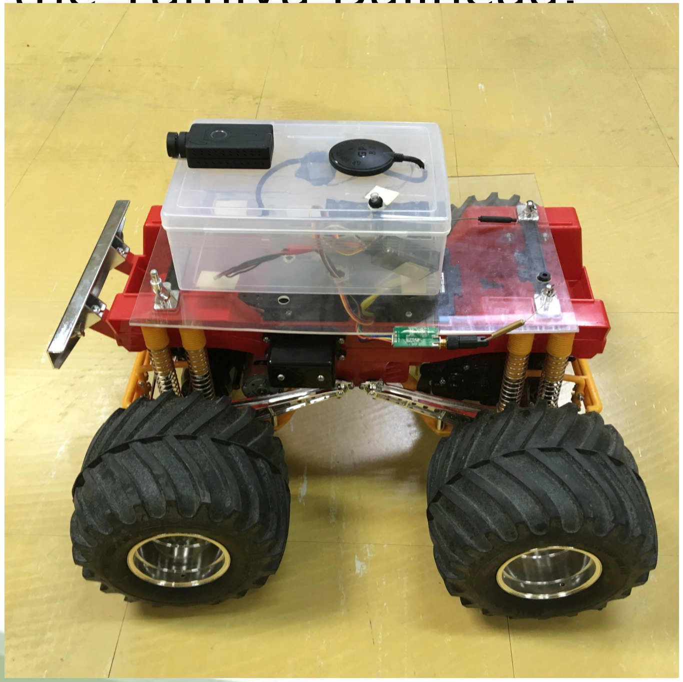
Hardware

- PixHawk has PX4 as its firmware.

- The test rig is mounted on top of RC vehicle, the Tamiya Bullhead.



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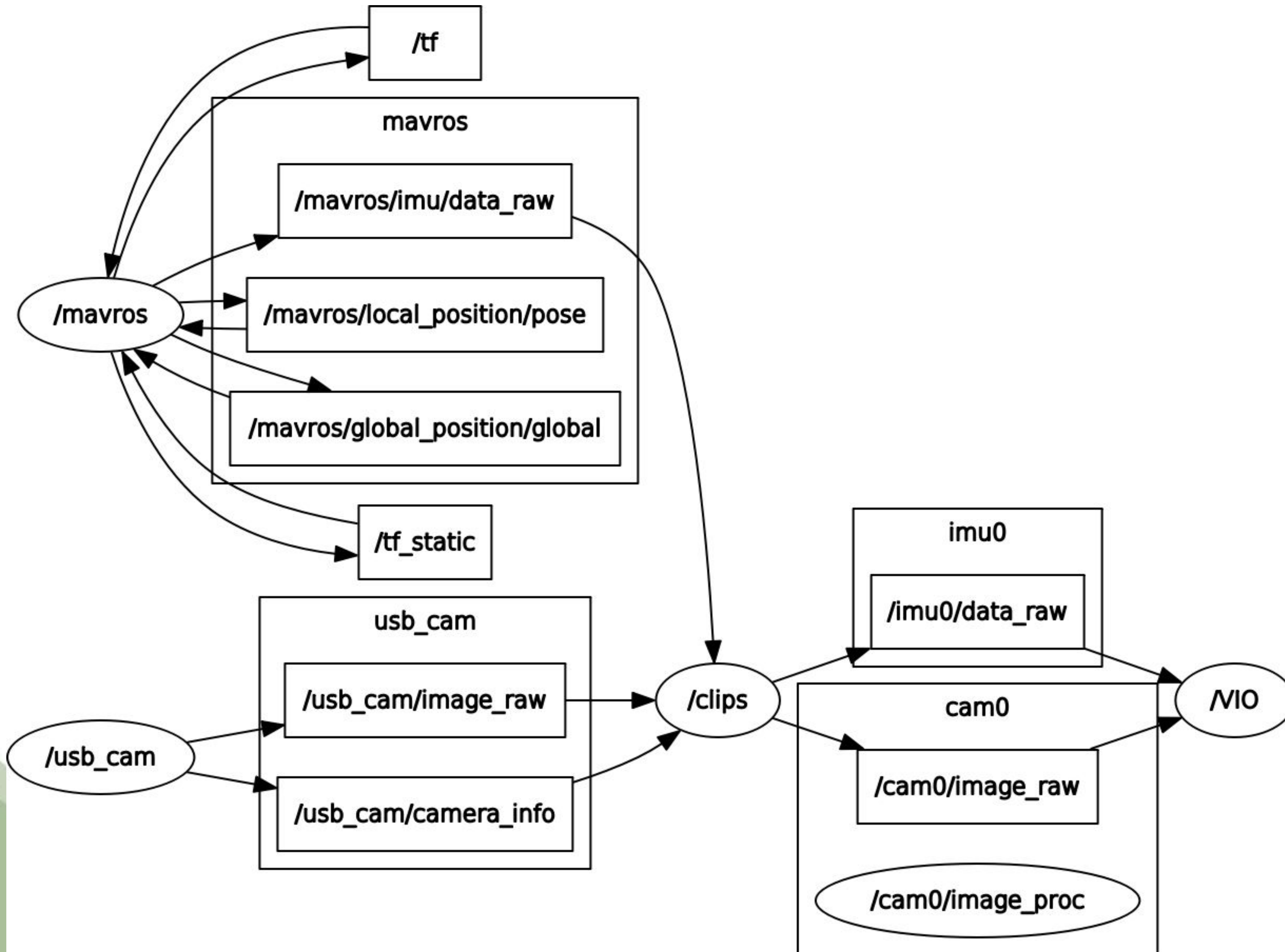
Software

- Robot Operating System (ROS) version Kinetic.
- Four ROS packages running on the test laptop.
  - usb_cam: Modified to support H264 streams.
  - mavros: Communicates with PixHawk using MAVLINK protocol.
  - clips: A new middleware layer to ensure at least one IMU measurement is present between each pair of image frames.
  - LearnVIORB: Modified to publish pose, point clouds, and tf information.

Software


/tf
mavros
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imu0
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usb_cam
/usb_cam/image_raw
/clips
/VIO
cam0
/usb_cam
/usb_cam/camera_info
/cam0/image_raw
/cam0/image_proc

Software (usb_cam)

- Mobius Maxi supports H264 hardware encoding.
- Video stream captured through H264 stream is smoother and supports higher framerates than raw stream.
- The library libavutils used by usb_cam has support for H264 streams.
- Added support for h264 pixel format.

Software (mavros)

- The PixHawk connection is shown as serial port /dev/ttyACM0 on the test laptop.
- The baud rate is 921600.
- PX4 publishes coordinates using the NED convention.
- mavros handles the conversion of NED coordinates to ENU coordinates to use with ROS.
- sys_time mavros plugin handles time synchronization between the host and the remote flight controller.

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Software(sys_time)

- A timesync message M is sent at a consistent frequency from the host system to FCU with with timestamp t_s.
- The remote FCU adds its timestamp t_c and replies.
- It is assumed that the round trip time for the message is equal in both ways,

$$t_{offset} = t_s + t_{now} - 2t_c$$

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Software(sys_time)

- t_{offset} is used for interpolating the time offset and time skew with a window of size n. k = {0 … n-1} is the index of the timesync message used for interpolation before convergence.

$$I = k/n$$

$$P = 1 - e^{\frac{1}{2}\left(1 - \frac{1}{(1-I)}\right)}$$

$$\alpha = P \times \alpha_f + (1 - P) * \alpha_i$$

$$\beta = P \times \beta_f + (1 - P) * \beta_i$$

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Software(sys_time)

- Online exponential smoothing filter is used to calculate interpolated time offset t and time skew t_{skew}.

$$t_k = \alpha \times t_{offset} + (1-\alpha) \times (t_{k-1} + t_{skew_{k-1}})$$

$$t_{skew_k} = \beta \times (t_k - t_{k-1}) + (1-\beta) \times t_{skew_{k-1}}$$

- If a maximum number of consecutive observations are received that is higher than a threshold deviation from the present estimate, the interpolation is reset.

- If the interpolation has not converged, the intermediate t and t_{skew} are used.

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Software (clips)

- The IMU and camera are not tightly bound.
- At least one IMU measurement between any two consecutive image frames is necessary for VIORB to predict the next keyframe location.
- This custom package which I created ensures that there is IMU measurement between two image frame.
- Drops the image frame if IMU measurement is not received.

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Software (LearnVIORB)

- LearnVIORB is a community-developed implementation of Visual Inertial ORB SLAM.
- I added support for publishing pose, point cloud, and tf information as ROS topics.
- I referred to the open source project ORB_SLAM2_CUDA (Nguyen)

Software(PX4 firmware)

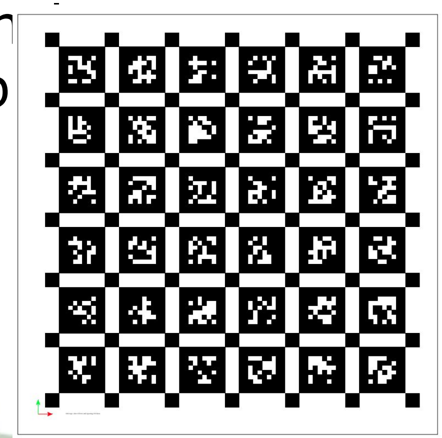
- PX4 by default does not support more than 50 Hz IMU rate.
- In the source code ROMFS/px4fmu_common/init.d/rcS had to be edited and re-compiled to increase IMU measurement rate to 200 Hz.

Calibration

- Camera intrinsic parameters were calibrated with the ROS camera_calibration package, using a checkerboard pattern.

- Noise density, and random walk for the accelerometer and gyroscope was calculated using kalibr_allan through Allan variance method.

- Camera-to-IMU tran as calculated using kalibr tool, using ap MU noise analysis results.



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Integration

- A configuration yaml file configured with the results of calibration.

- IMU noise density and random walk constants in LearnVIORB src/IMU/imudata.cpp was updated.

- A launch file in clips starts usb_cam, mavros, and clips and publishes /imu0/data_raw and /cam0/image_raw.

- The topics can be stored in a bag file or directly subscribed by LearnVIORB.

Experimental Results

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Experiment Environment

- The test rover was manually controlled in indoor and outdoor environment.
- The test laptop was connected to the camera and the flight controller.
- The data collected was stored in a ROS bag file.
- The bag file was replayed and the collected data was used to run VIORB and ORB SLAM.

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Indoor Experiment

- The test rover was run in indoor environment for 170 seconds.
- The number of ORB features to extract was kept at 2000.
- The approximate length of the path was 17 meters.

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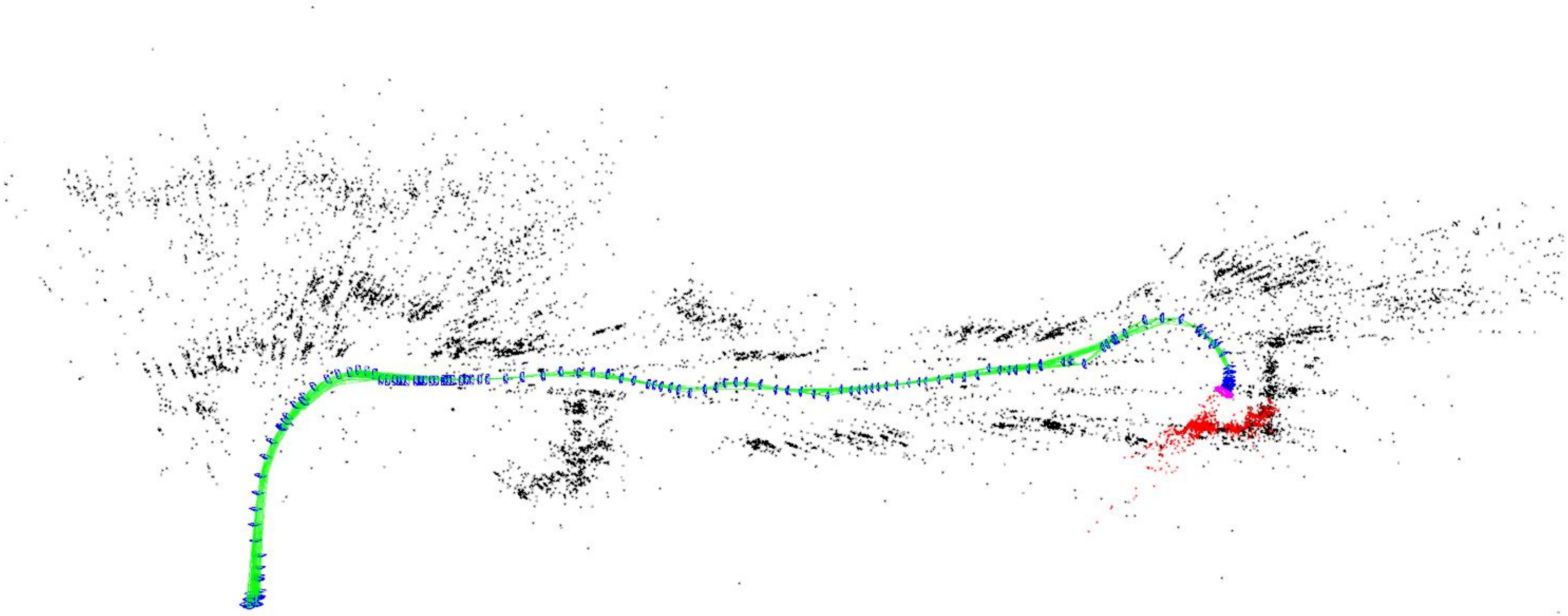
Indoor Experiment

- VIORB SLAM relocalized a couple of times.
- VIORB SLAM lost tracking and could not be relocalized after 117.5 seconds.
- ORB SLAM was more robust and did not lost track.
- ORB SLAM reported path length of 3.92 meters. VIORB SLAM reported path length of 13.875 meters.

Indoor Experiment (VIORB SLAM)



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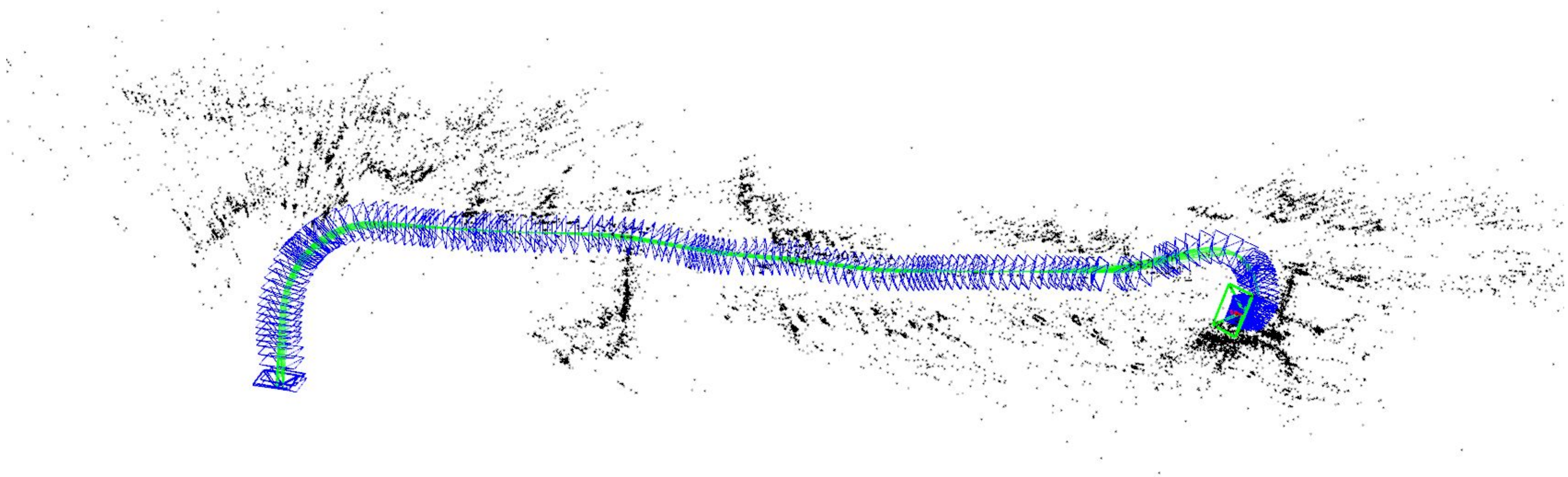
Indoor Experiment (ORB SLAM)



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Indoor Experiment

Algorithm	Total Time	IMU initialization time	Duration tracked	Poses	Path length
ORB	170s	NA	161.148s	249	3.920m
VIORB	170s	15s	117.459s	155	13.875m

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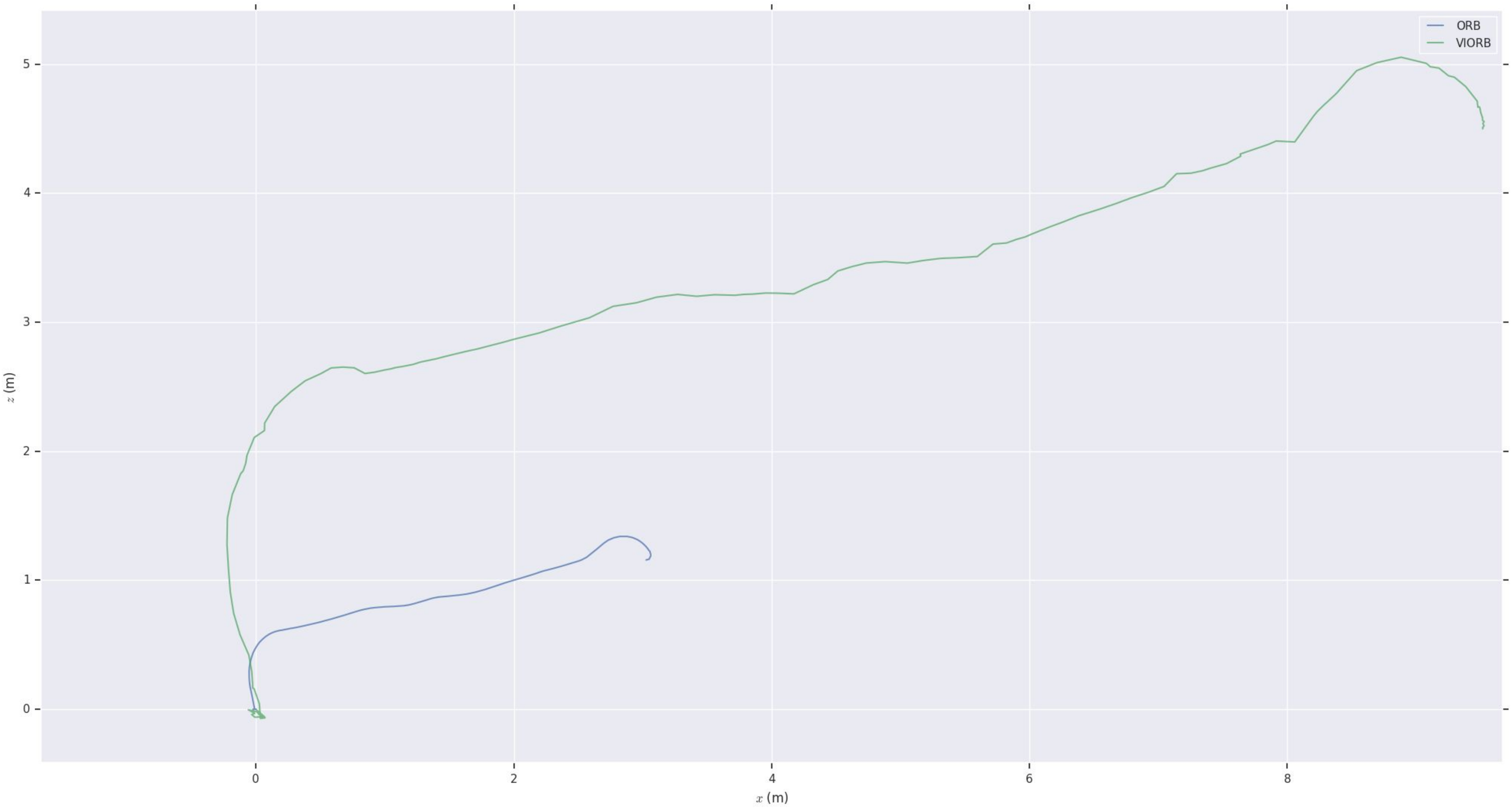
Indoor Experiment



Outdoor Experiment

- The test rover was run in outdoor environment for 174 seconds.
- The number of ORB features to extract was kept at 2000.
- The rover faced more jerky movements than the indoor experiment.

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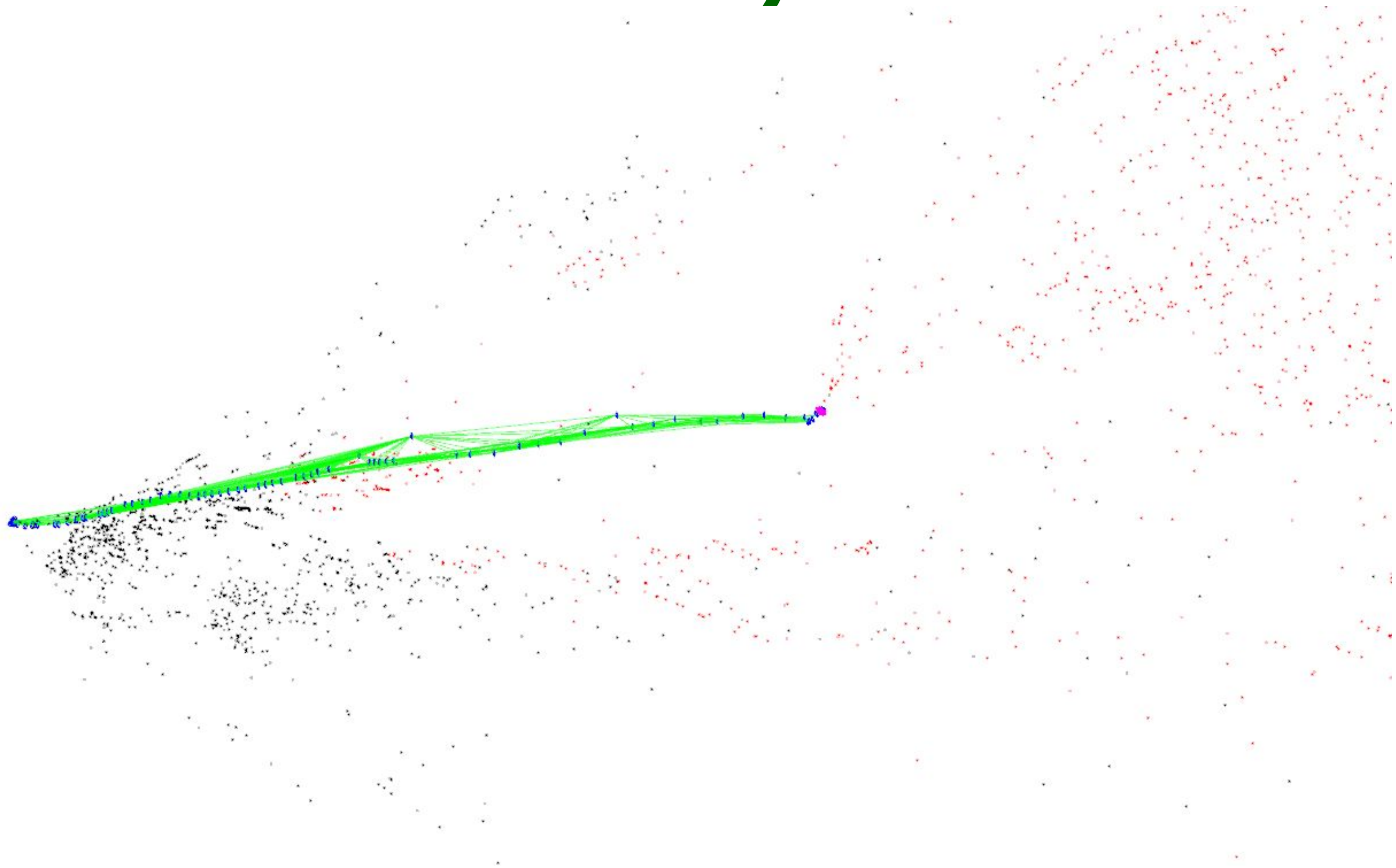
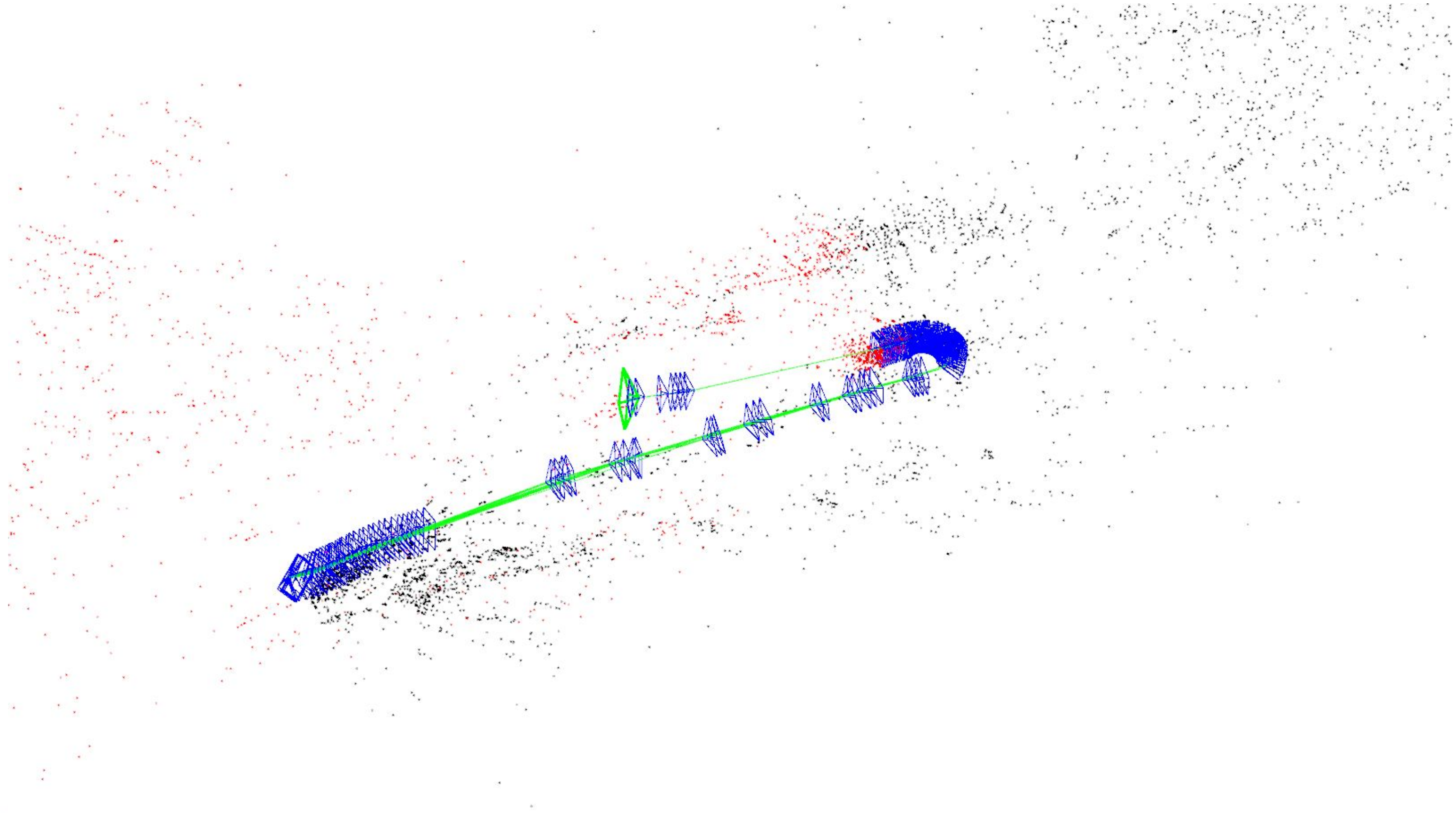
Outdoor Experiment

- VIORB SLAM relocalized a couple of times.
- VIORB SLAM lost tracking and could not be relocalized after 96.871 seconds.
- ORB SLAM was more robust and did not lost track.
- ORB SLAM reported path length of 3.15 meters. VIORB SLAM reported path length of 14.427 meters.

Outdoor Experiment (VIORB SLAM)



Outdoor Experiment (ORB SLAM)



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Outdoor Experiment

Algorithm	Total Time	IMU initialization time	Duration tracked	Poses	Path length
ORB	174s	NA	160.637s	134	3.150m
VIORB	174s	30s	96.871s	85	14.427m

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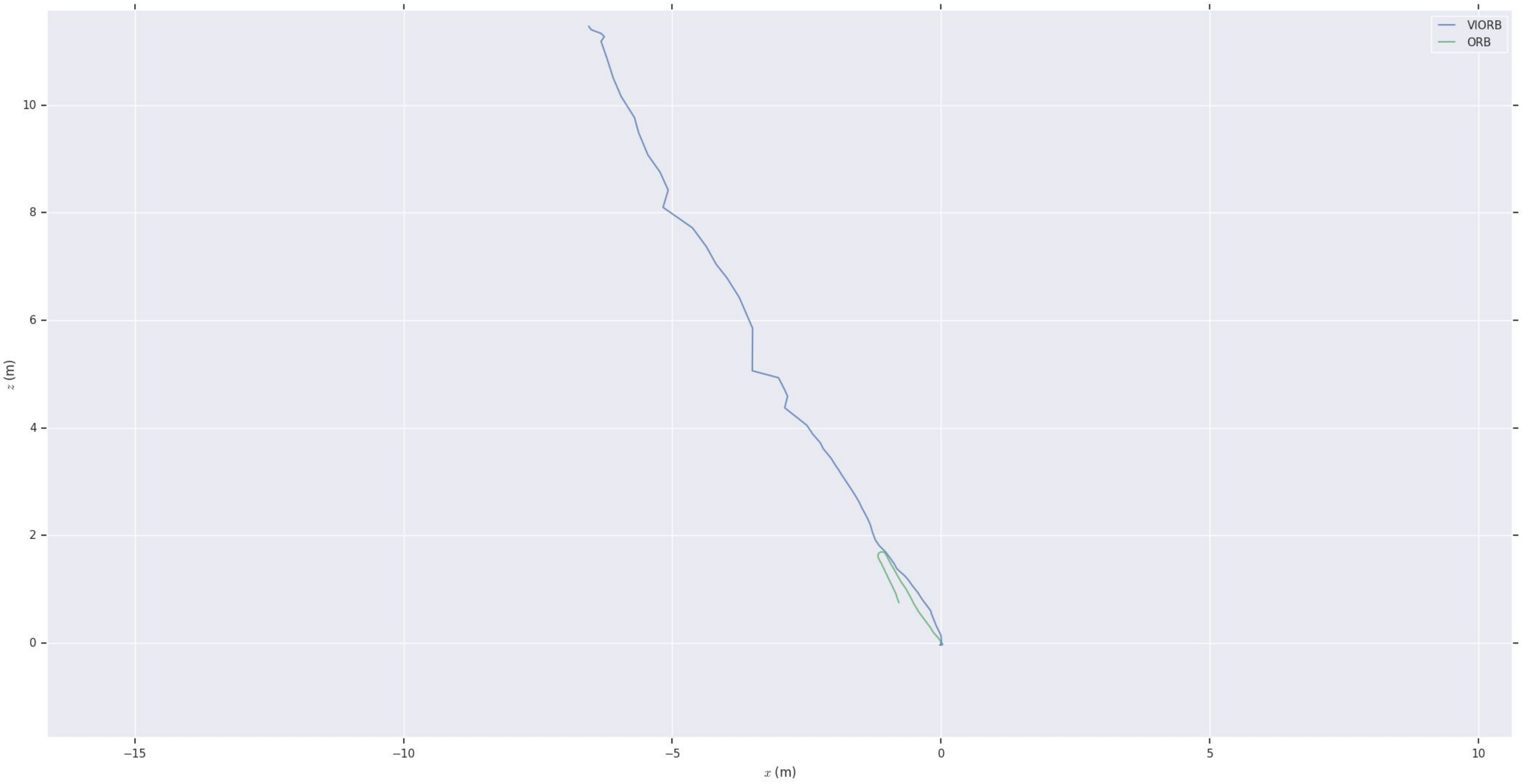
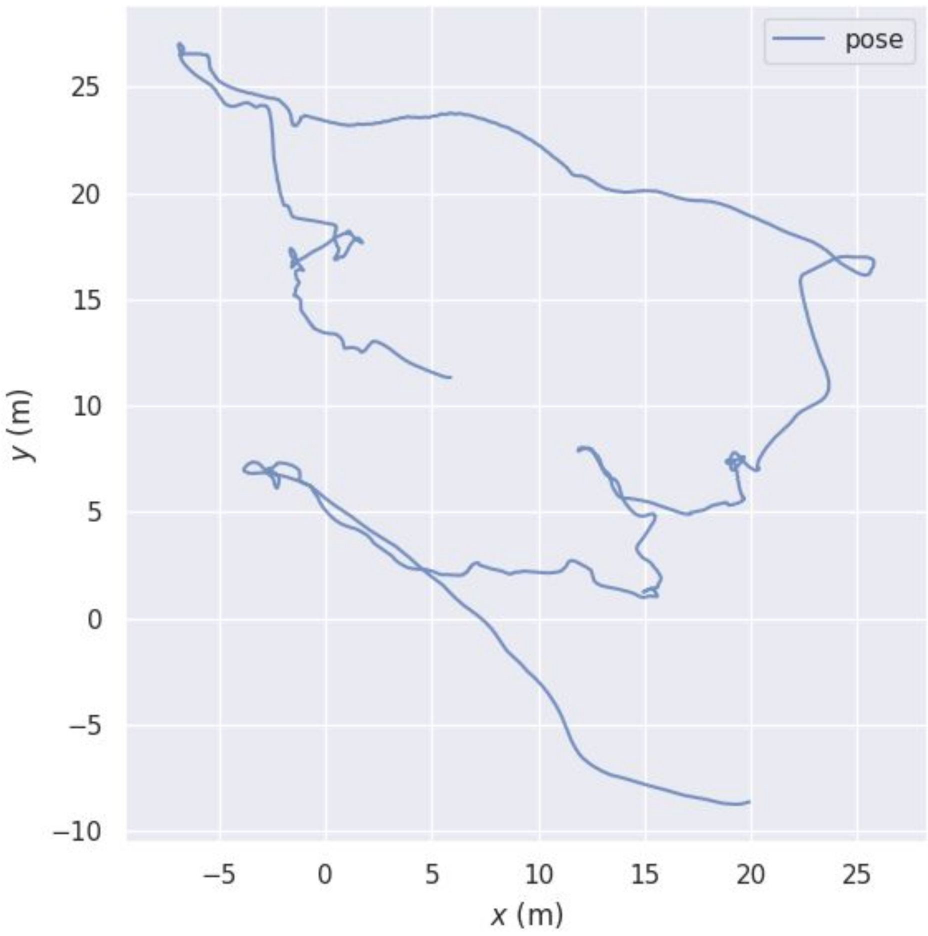
Outdoor Experiment



Outdoor Experiment



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Conclusion and Recommendations

Conclusion

- VIORB SLAM is closer to the ground truth in approximating the scale of the constructed map than ORB SLAM.
- ORB SLAM is more robust than VIORB SLAM and does not lose track as easily.
- Setting up VIORB SLAM is more complex than ORB SLAM. This increased complexity may be one reason VIORB SLAM is less robust than ORB SLAM.

Conclusion

- The interpolated time offset interpolated by sys_time plugin may not represent the actual time offset. This may affect VIORB SLAM.
- The GPS module attached to the PixHawk drifts and is not precise over short distances.
- VIORB and ORB SLAM publish pose in a zyx coordinate system, where the z axis protrudes out in the front direction of the camera or the IMU.

Recommendations

- Proper calibration may make VIORB more robust.
- Replacing the internal IMU in PixHawk with an external IMU having low noise, may make the calibration more accurate.
- A tightly coupled camera-IMU system, where the camera is triggered through the host computer or the flight controller may help in time synchronization.
- Reducing jerky movements through mechanical means while the rover is moving on the ground may make it more robust.

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Thank You