



THE UNIVERSITY OF WESTERN AUSTRALIA

# Evaluation of 3D SLAM on a Shuttle Bus Equipped with Limited Sensors Using Sensor Fusion and Calibration Techniques

Lee Le (23011365)

# Contents

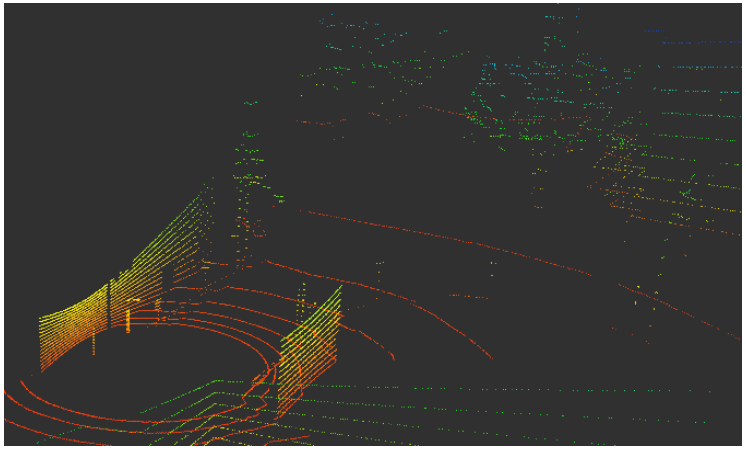
- Brief Introduction
- Problem Statements
- Calibration Frameworks
- Experiments Setup
- Results
- Limitation and Discussion

# Brief Introduction

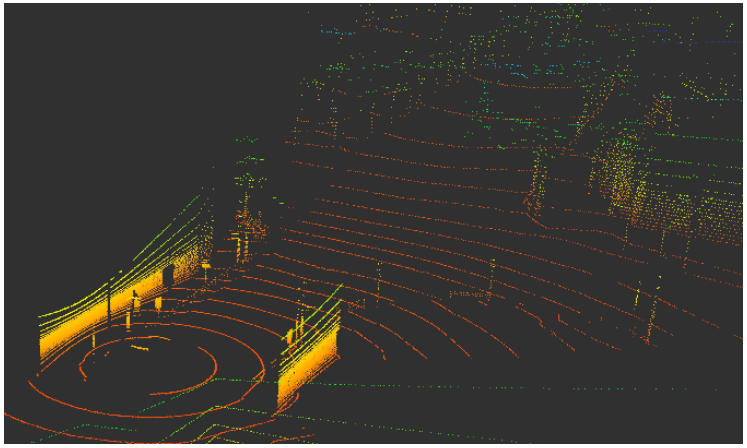
- Simultaneous Localization and Mapping remains one of the most robust in localization.
- Especially 3D SLAM but usually requires high-end sensors.

*https://www.flyeye.io/drone-acronym-tof/

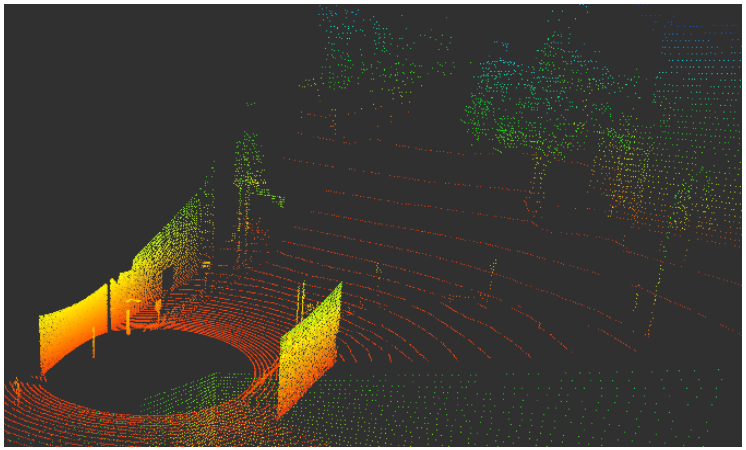
# Resolutions of Various Velodyne LiDARs



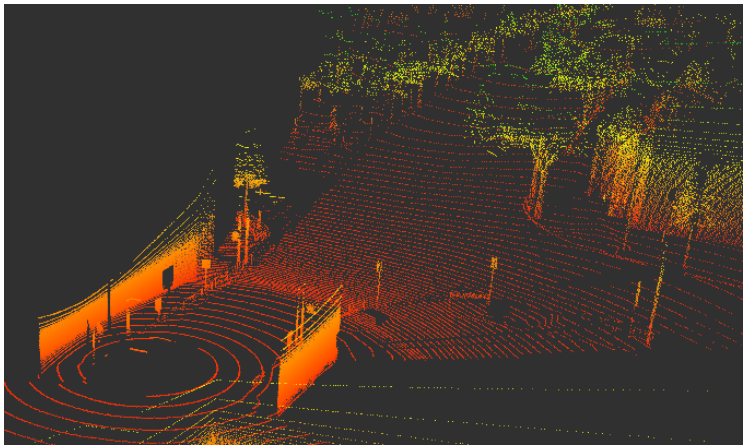
VLP-16



VLP-32



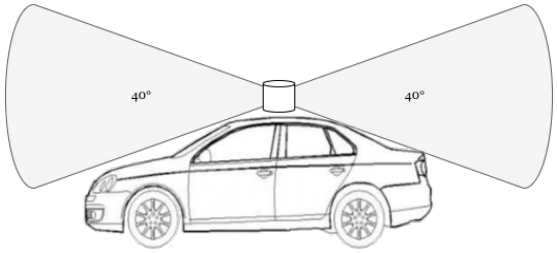
OS-64

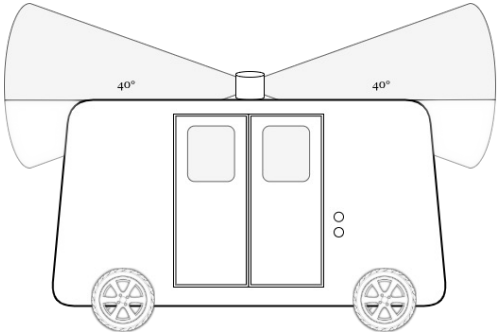


VLP-128

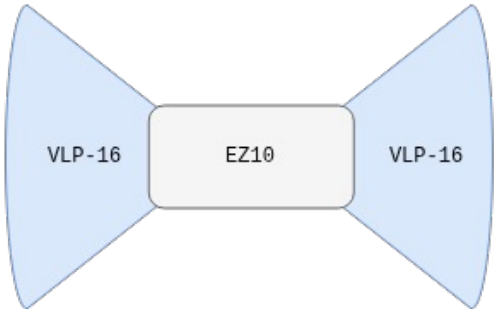
*AWSIM Simulation on Unity

# Design of Sedans vs. Shuttles








HFoV: 140°
VFoV: 40°
Range: 200m
Frequency:10Hz

*https://www.pixmoving.com/

# Datasets

| Datasets | KITTI | LIO-SAM | *Wan et al., 2018 | **Ours** |
|---|---|---|---|---|
| LiDAR | HDL-64E | VLP-16 | VLP-32 | **VLP-16 x2** |
| HFoV | 360° | 360° | 360° | **140°** |
| VLayers | 64 | 16 | 32 | **16** |
| IMU | IGM-A1 | 3DM-GX5-25 | RT3000 v3 | **Xsens MTi-10** |
| Frequency | 200 $Hz$ | 1000 $Hz$ | 250 $Hz$ | **100 Hz** |
| Gyro Noise | 0.3 $°/\sqrt{hr}$ | 0.3 $°/\sqrt{hr}$ | 0.2 $°/\sqrt{hr}$ | **1.8** $°/\sqrt{hr}$ |
| Acceleration | 50 µg/$\sqrt{Hz}$ | 20 µg/$\sqrt{Hz}$ | 8.5 µg/$\sqrt{Hz}$ | **60** µg/$\sqrt{Hz}$ |
| Grade | Tactical | Industrial | Tactical | **Industrial** |

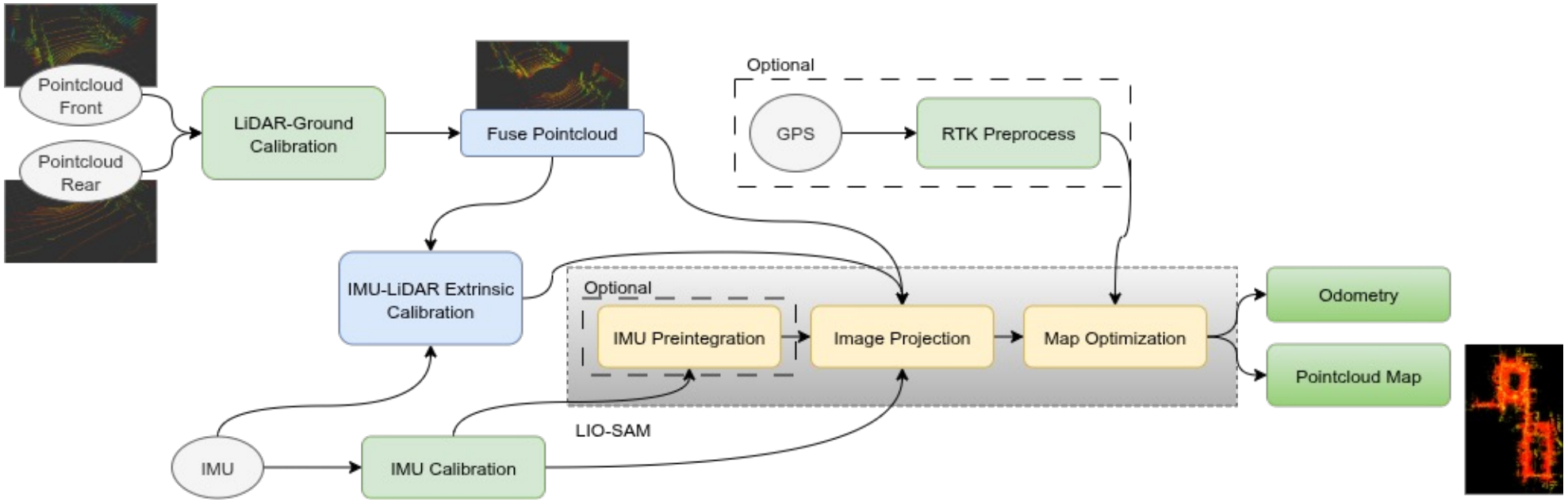
*G. Wan, X. Yang, R. Cai, H. Li, Y. Zhou, H. Wang, and S. Song. robust and precise vehicle localization based on multi-sensor fusion in diverse city scenes. pages 4670–4677, 2018.

# Objectives

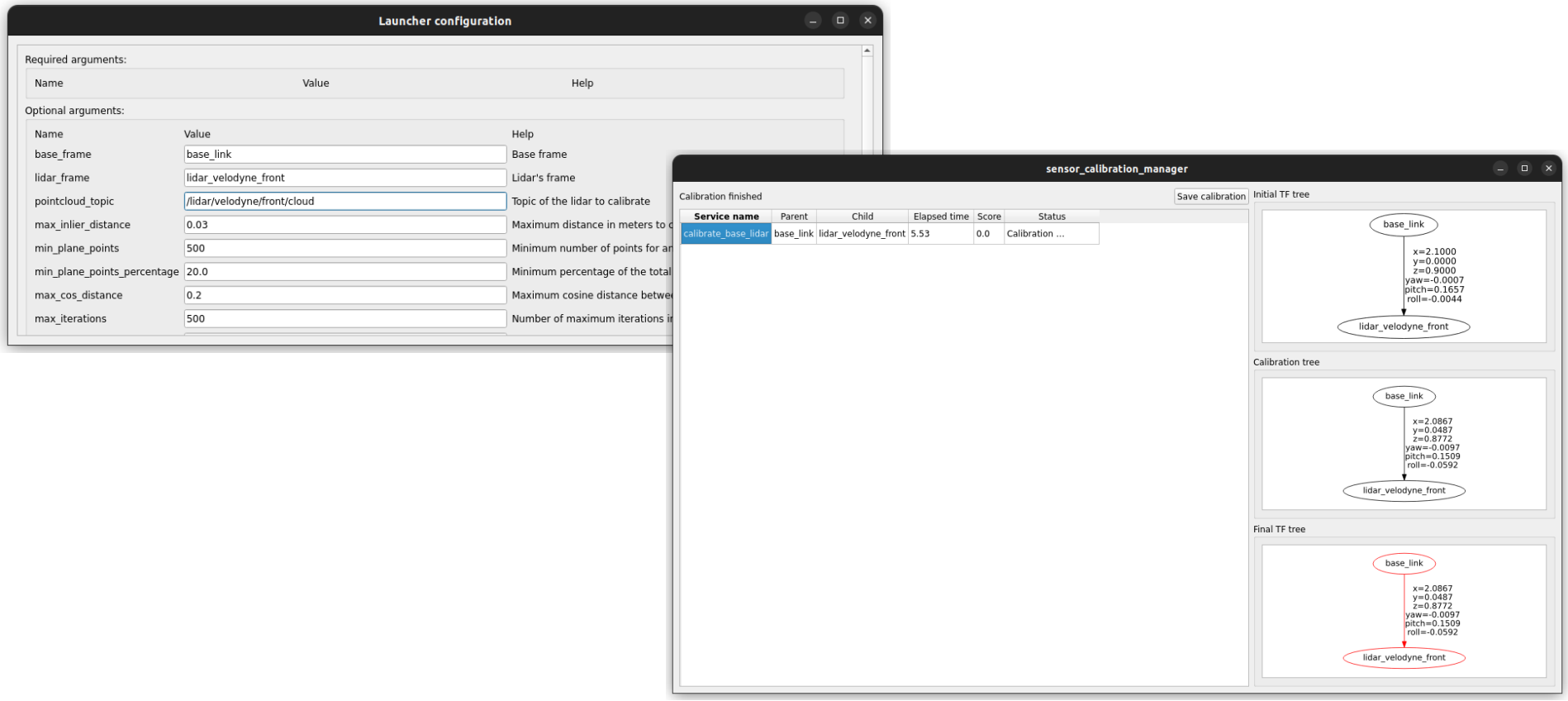
- Development of calibration procedures for multiple Velodyne sensors with limited Field of View (FoV).
- Implementation of a point cloud fusion algorithm utilizing the PCL library to extend the effective FoV.
- Experimental validation of the proposed methods in unbalanced and highly complex environments.
- Comprehensive benchmarking of the system's 3D SLAM performance.

*https://autowarefoundation.github.io/autoware-documentation/main/design/

# System Framework

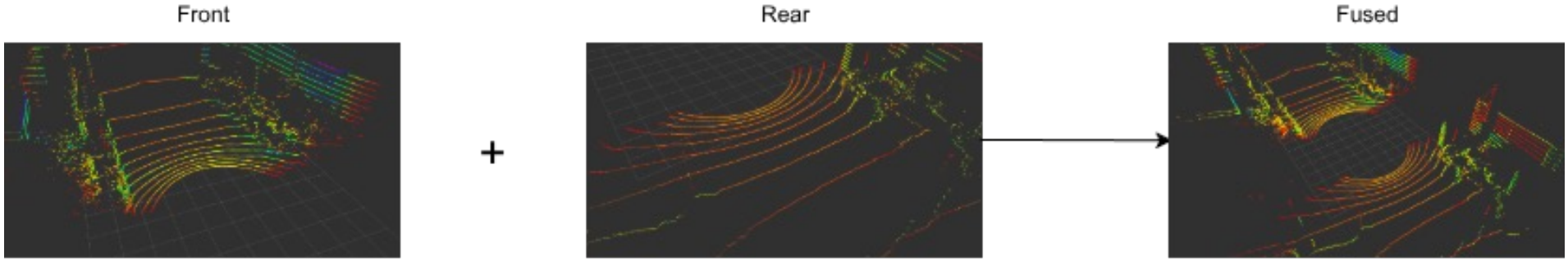


# Ground Plane LiDAR Calibration



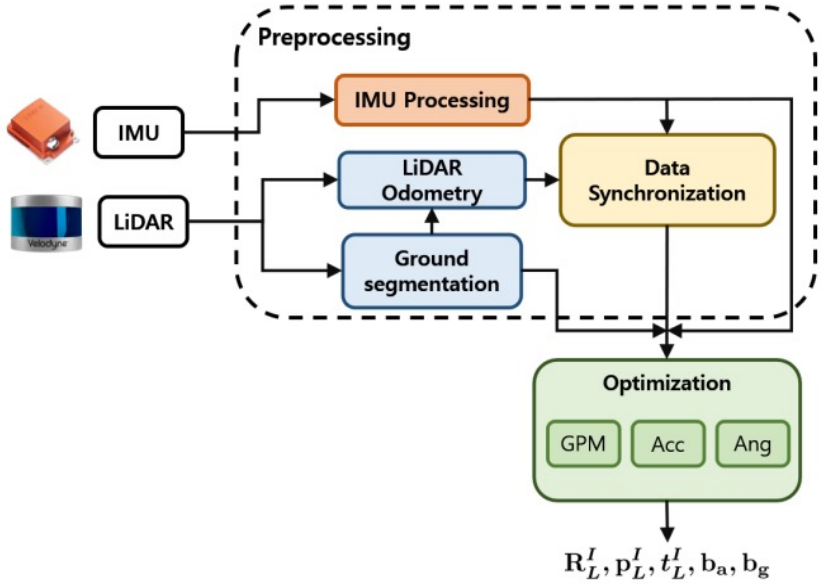
# Fuse Pointcloud

- Set up the Velodynes to be same frequency (10Hz).
- Apply certain threshold so that the fused frame is within a certain time difference (10ms)
- The Pointcloud is fused in relation to the base_link.



# LiDAR-IMU Calibration

- Use GRILL-Calib
- Overview of GRILL-Calib system framework




*TaeYoung Kim, Gyuhyeon Pak, and Euntai Kim. Gril-calib: Targetless ground robot imu-lidar extrinsic calibration method using ground plane motion constraints. IEEE Robotics and Automation Letters, 9(6):5409–5416, 2024.

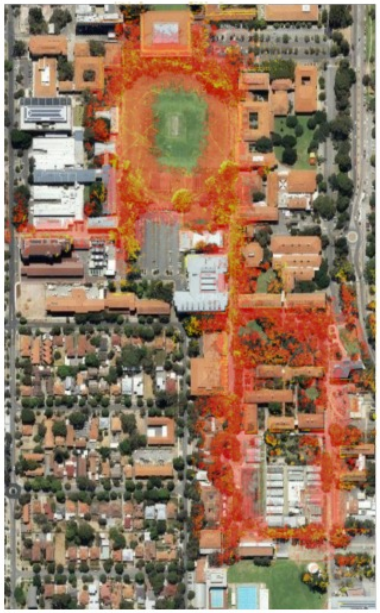
# Experimental (Dataset)

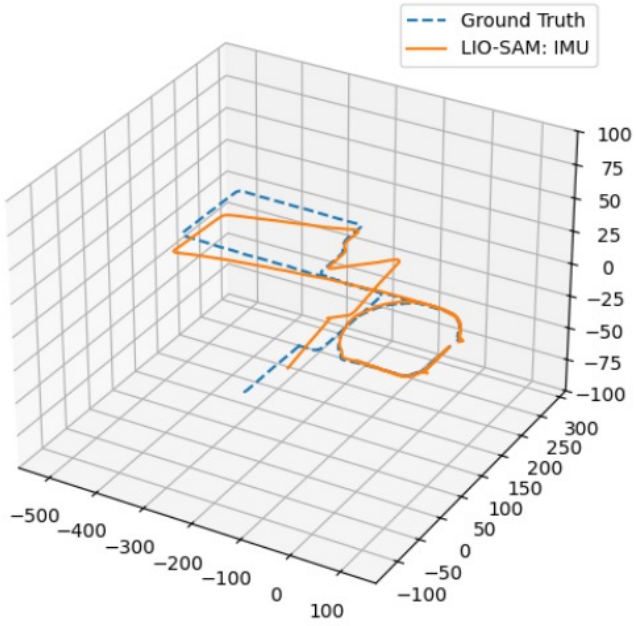
- RTK with 10 centimeters covariance as ground truth.
- The trajectories then compared with the ground truth using Root Mean Squared Error (RMSE).
- The metrics only involve 2D coordinates

| Information | Value |
|---|---|
| Front-Velodyne Scans | 22329 |
| Rear-Velodyne Scans | 22328 |
| Velodyne Frequency | 10 $Hz$ |
| Elevation | 2 $m$ |
| Trajectory Length | 2.36 $km$ |
| Speed | 1.5 $m/s$ |
| IMU Frequency | 100 $Hz$ |
| GPS + RTK Frequency | 5 $Hz$ |

# Results

| | IMU Preintegration | Single LiDAR | | | Fused LiDARs | | Calibrated Fused LiDARS | | |
|---|---|---|---|---|---|---|---|---|---|
| | | IMU | IMU+GPS | IMU+RTK | IMU+RTK+NoGC | IMU+RTK+NoTC | IMU | IMU+GPS | **IMU+RTK** |
| Mapping | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1st Loop Closure | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2nd Loop Closure | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ |
| RMSE | Failed | Failed | Failed | Failed | 4.57 | 2.94 | 12.22 | 2.41 | ***1.76** |



# Limitation and Future Works

- Limitation:
  - Only tested with slow speed
  - Failed to integrate IMU pre-integration
  - Still rely on GPS Coordinates
- Future Works:
  - Better Model for IMU pre-integration
  - Test with relatively high-speed area