UNIVERSITÀ DEGLI STUDI DI PADOVA

Design and prototyping of a Guidance Navigation and Control system suitable for a lunar rover

Simone Fortuna - 38th Cycle

Supervisor: Prof. Marco Pertile
Co-supervisors: Sebastiano Chiodini, Andrea Merlo, Andrea Valmorbida

Admission to the 2nd year - 13/09/2023

PhD Objectives

Design and prototyping of a Guidance Navigation and Control system suitable for a lunar rover

PNRR

1. Design and HW implementation of the lunar rover GNC system
2. SW and algorithms development for navigation and control tasks
3. SW/HW tests and navigation strategies validation

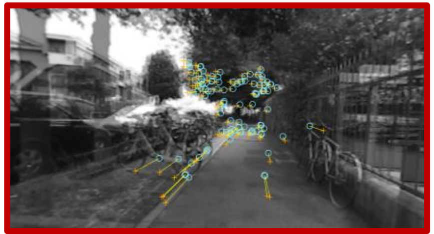
1st year activities

Main Activities:

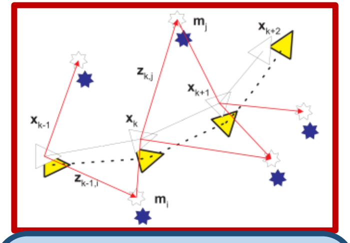
- Individual study of Visual SLAM (focusing on ORBSLAM3)
- Courses on Python, C++, AI, ROS
- Work on LiDARs with MORPHEUS rover
- IEEE Summer School on Multi-Robot Systems

Visual SLAM

Sensor Data

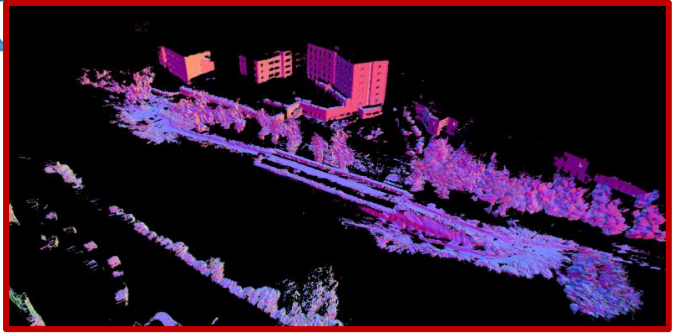


FRONTEND
Visual Odometry

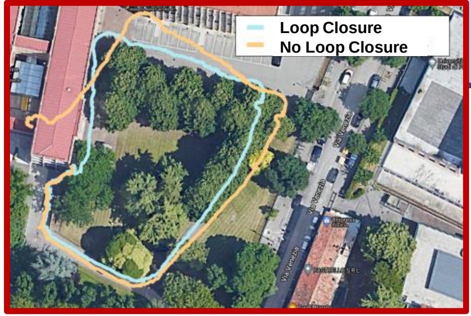


BACKEND
Filters
Optimization

Reconstruction



Loop Closure



Visual SLAM

Feature Methods

- Extracting features (keypoints + descriptors)
- Feature matching
- ✓ Frequent illumination changes and high-performing hardware

Direct Methods

- Track pixels motion
- Optimization solver
- Constant brightness
- ✓ High real-time requirement
- ✓ Semi-dense / Dense maps

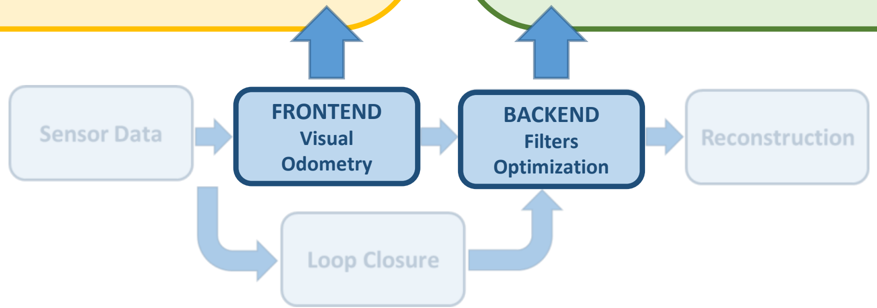
Extended Kalman Filters

Bundle Adjustment & Graph Optimization

Problem: Estimating the state of the entire system from noisy input data and calculate their uncertainty

- Current estimated state → update it with new data
- ✖ Linearization error and noise Gaussian distribution assumptions

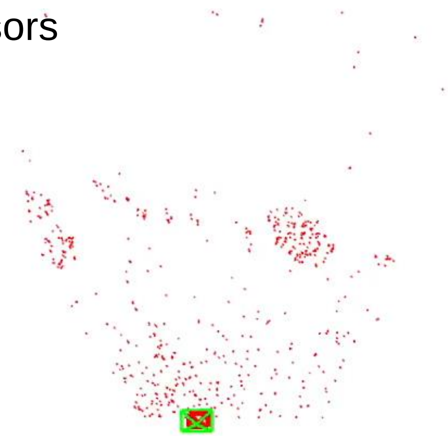
- Record all data + looking for best trajectory&map
- ✖ Computationally expensive

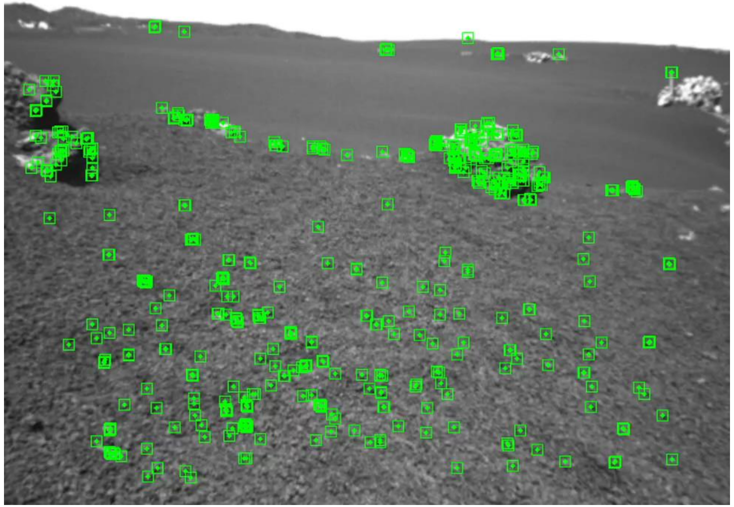


ORBSLAM algorithm

- ✓ Supporting various sensors
- ✓ ORB features
- ✓ Three-threads structure
- ✓ Excellent LC algorithm
- ✗ Expensive
- ✗ Sparse Feature Points

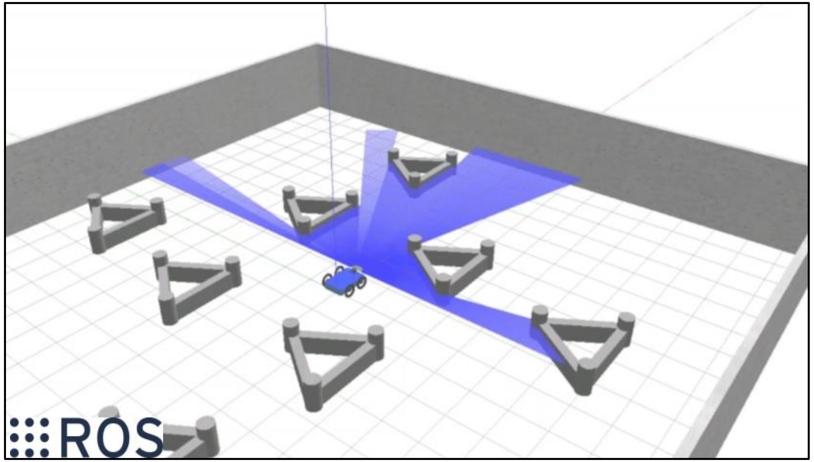
  → Sparse Maps

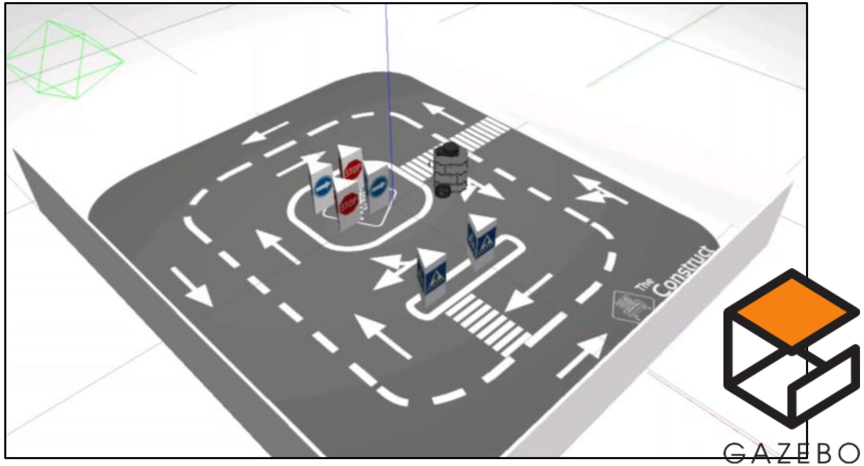




Why ROS?

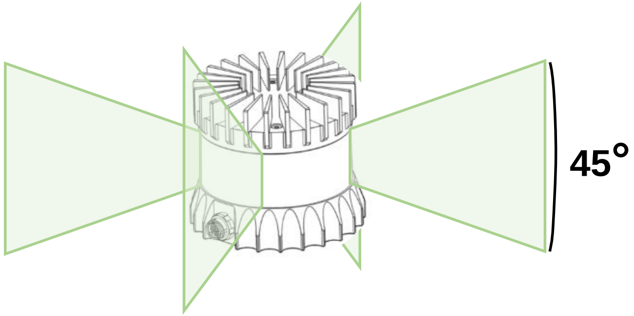
- Peer to peer
- Distributed
- Multi-lingual
- Light-weight
- Free and open-source



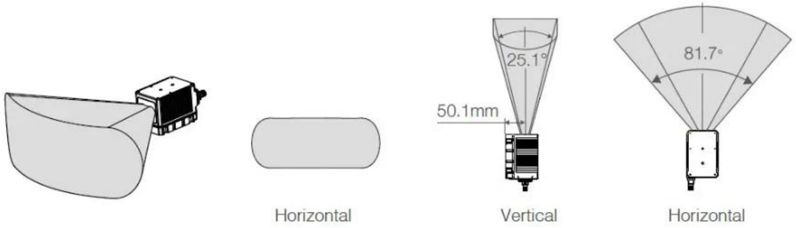


LiDAR Comparison

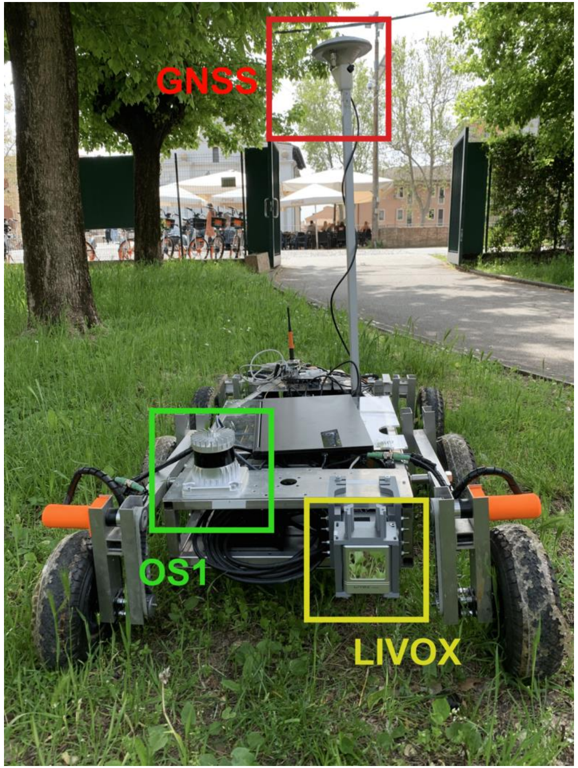
360 FOV Scanning LiDAR
Ouster OS1 - 32 channels



Non-Repetitive Scanning LiDAR
Livox Horizon

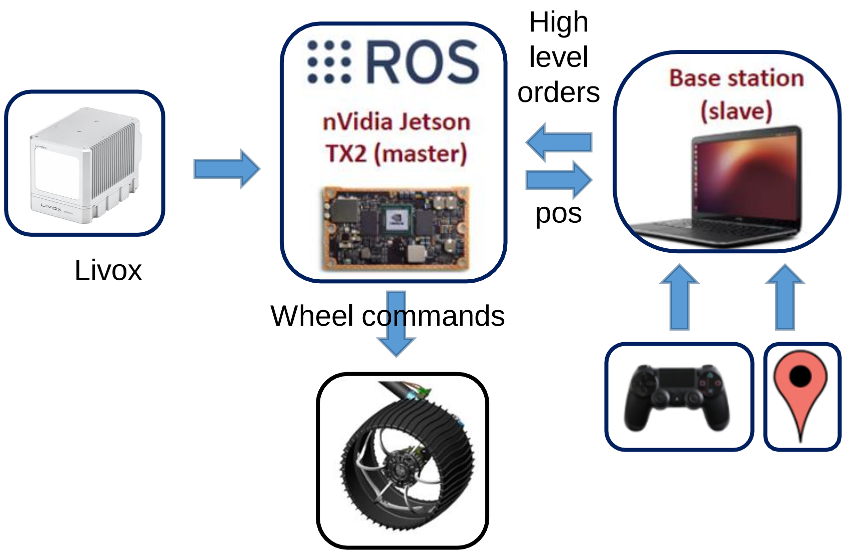


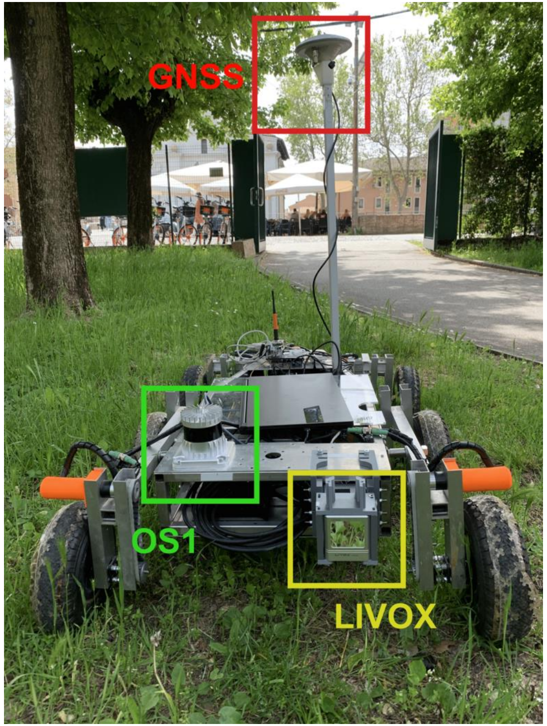
LiDAR Comparison



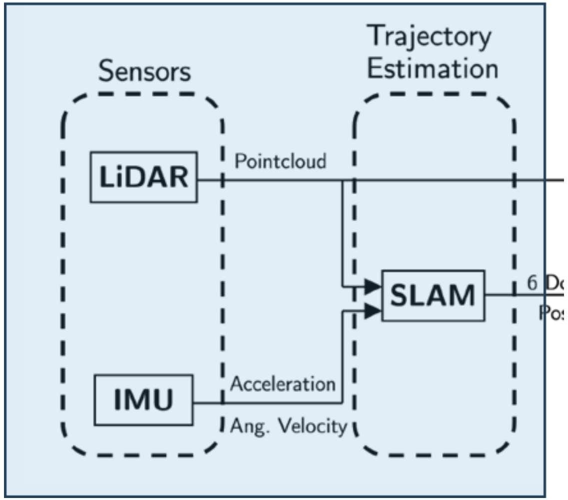
	Livox Horizon	Ouster OS1 32 channel
Maximum Detection Range	90 m @ reflectivity 10% 130 m @ reflectivity 20% 260 m @ reflectivity 80%	90 m @ reflectivity 10% 170 m @ reflectivity 80%
Minimum Detection Range	0.5 m	0.5 m
FOV (H×V)	81.7° × 25.1°	360° × 45°
FOV Coverage[1]	60% @ 0.1 s 98% @ 0.5 s	NA[1]
Point Acquisition Rate	> 240,000 points/s	1,310,720 points/s
Random Error $(1-\sigma)$	0.02 m @ 20 m	0.05 m @ 0.5 m 0.1 m @ 90 m
	IMU BMI0881	**IMU IAM-20680HT**
Resolution	Accelerometer (A): 0.09 mg Gyroscope (G): 0.004°/s	Accelerometer (A): 0.06 mg Gyroscope (G): 0.008°/s
Measurement range	(A) ± 3 g (G): ± 125°/s	(A) ± 2 g (G): ± 250°/s
Noise density (typ.)	(A): 175 $\mu g/\sqrt{Hz}$ (G): 0.014 $^\circ/s/\sqrt{Hz}$	(A): 135 $\mu g/\sqrt{Hz}$ (G): 0.005 $^\circ/s/\sqrt{Hz}$
Sample Rate	200 Hz	100 Hz

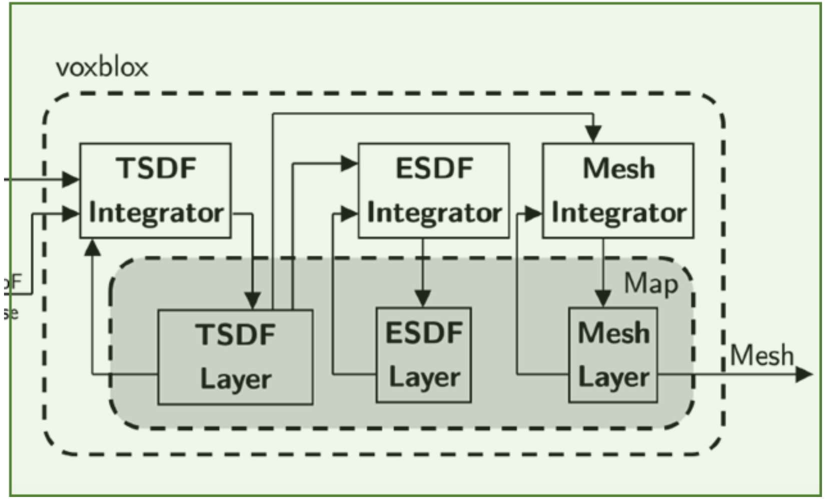
LiDAR Comparison





LiDAR Comparison – Nav Pipeline





Fast LiDAR-Inertial Odometry (FAST-LIO)

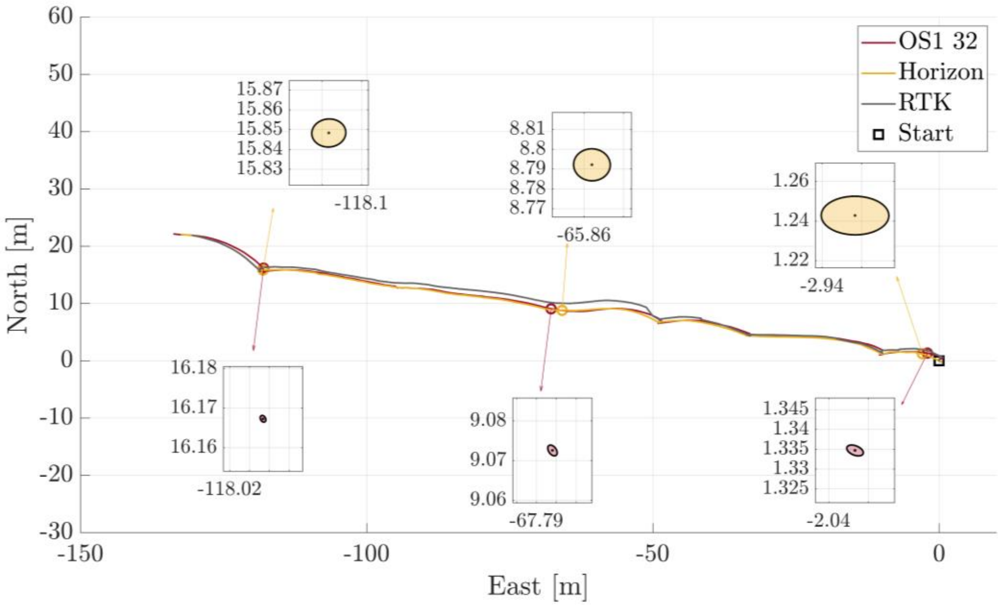
- Efficient and robust package
- Allows robust navigation in fast-motion, noisy or cluttered environments

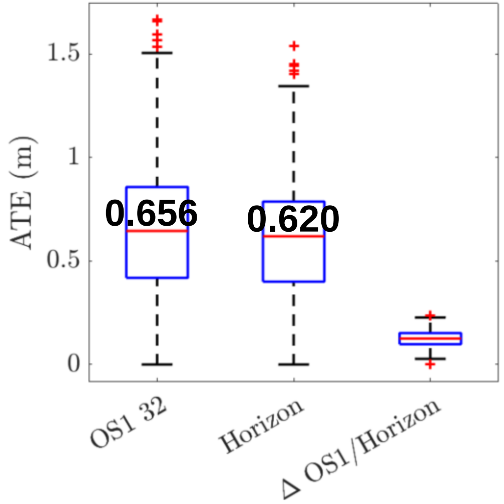
VOXBLOX

- Generates a three-dimensional volumetric map based on the **Truncated and Euclidean Signed Distance Field (TSDF and ESDF)**

LiDAR Comparison - Results

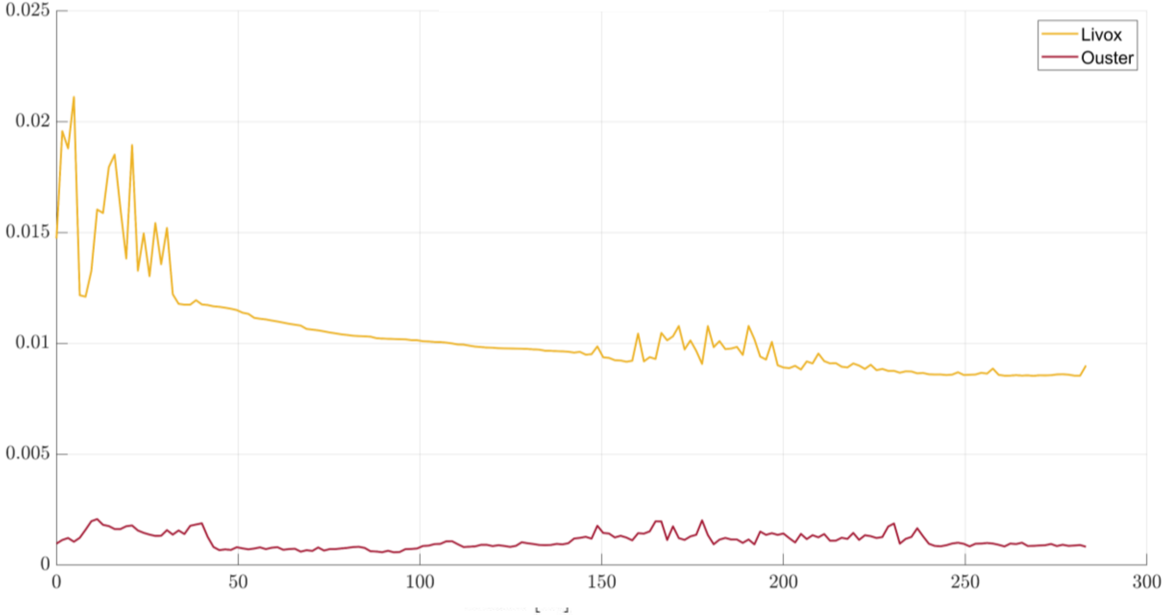
Trajectory comparison

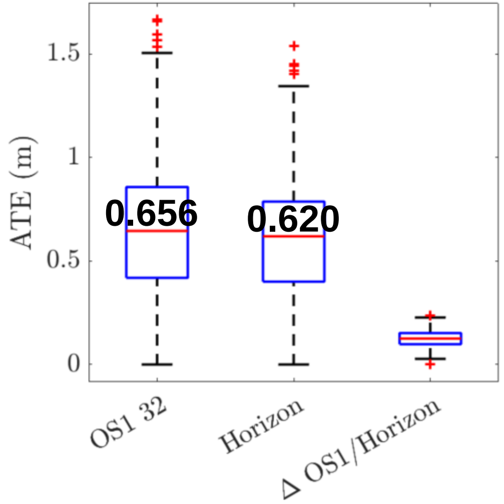




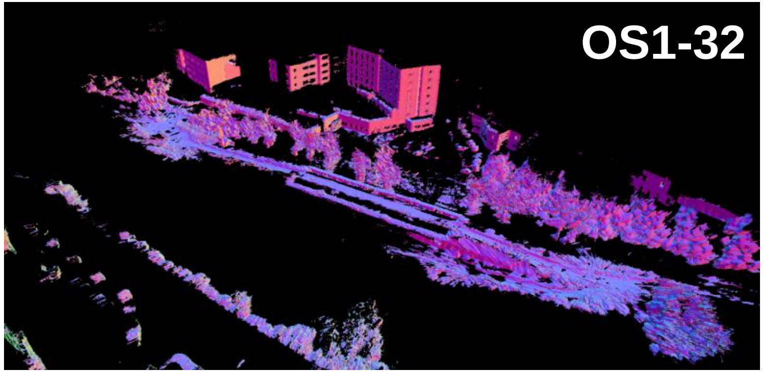
LiDAR Comparison - Results

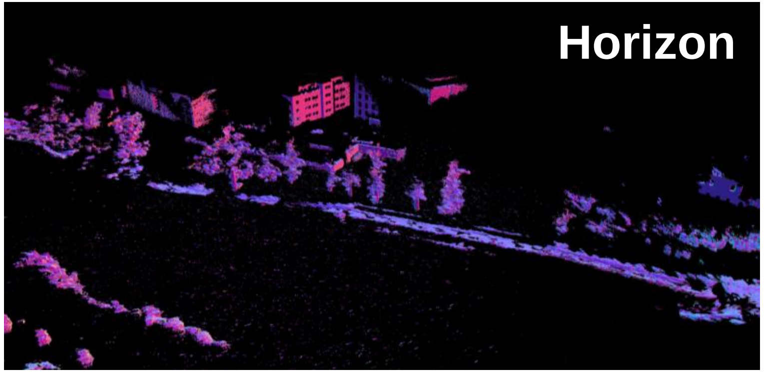
Comparison max eigenvalues

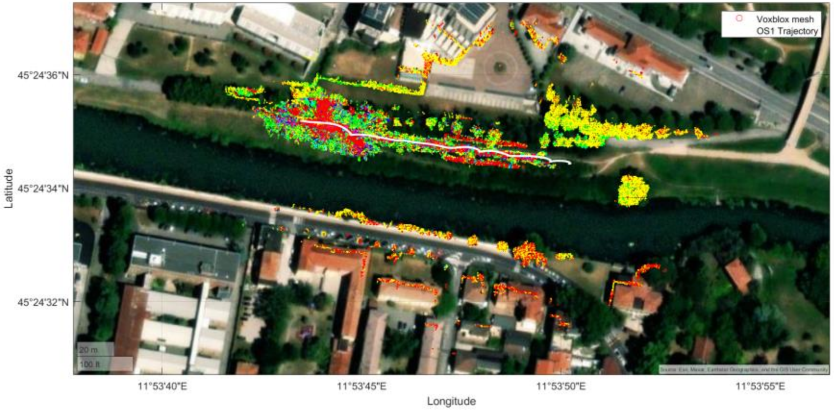


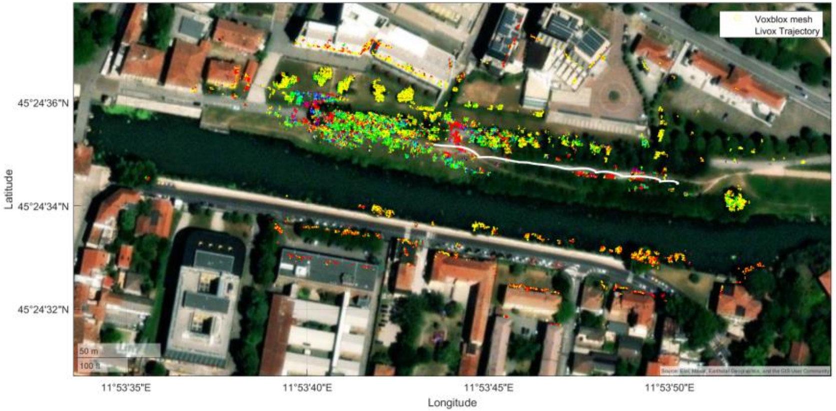


LiDAR Comparison - Results









LiDAR Comparison - Conclusions

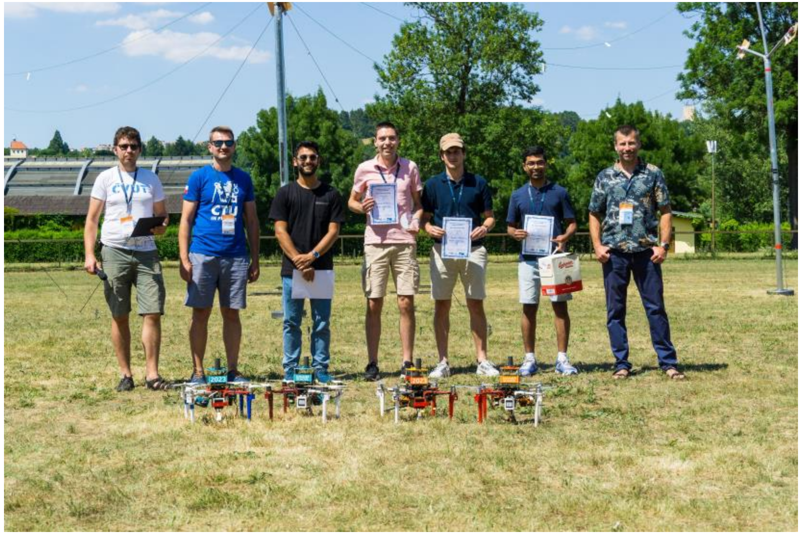
Conclusions

- OS1 LiDAR → ATE = 0.656 m
  Horizon LiDAR → ATE = 0.620 m
  Ouster/Horizon → 0.125 m

- Horizon LiDAR demonstrated slightly lower trajectory estimation error, likely due to lower random error in distance measurements and resulting in a denser point cloud within its field of view.

- However, OS1 LiDAR proved to be more reliable overall due to its 360-degree field of view, reducing the risk of losing track of features evenly distributed throughout the environment.

IEEE Summer School on Multi-Robot Systems



Università degli Studi di Padova

Timing

PHD STUDENT	Fortuna Simone	DATE	06/09/2023
PHD THESIS	Design and prototyping of a Guidance Navigation and Control system suitable for a lunar rover	ADMISSION TO	**Second year** in the Sciences, Technologies and Measurements for Space PhD Course

FIRST YEAR				SECOND YEAR				THIRD YEAR			
T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
O N D	J F M	A M J	J A S	O N D	J F M	A M J	J A S	O N D	J F M	A M J	J A S

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	**Skills Acquisition and Literature Review**	
1.1	Study of Visual SLAM	100%
1.2	Acquiring skills in programming and ROS framework	100%
1.3	Navigation sensors and strategies review	50%
1.4	Rover GNC systems/architectures review	70%
2	**GNC system design and prototyping**	
2.1	Use cases and requirements definition for the lunar rover	50%
2.4	Design of GNC architecture and hardware implementation	0%
3	**Navigation SW and algorithms development**	
3.1	Definition of navigation/locomotion strategies	0%
3.2	Navigation SW and algorithms development	0%
4	**SW/HW tests and navigation strategies validation**	
4.1	Test campaign	
4.2	Test results analysis	
5	**Thesis writing and reports/articles redaction**	
5.1	Writing reports	0%
5.2	Article redaction	10%
5.3	PhD Thesis	10%

Thanks for the attention

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