Exploiting spatio-temporal map segmentation for graph SLAM and frontier detection

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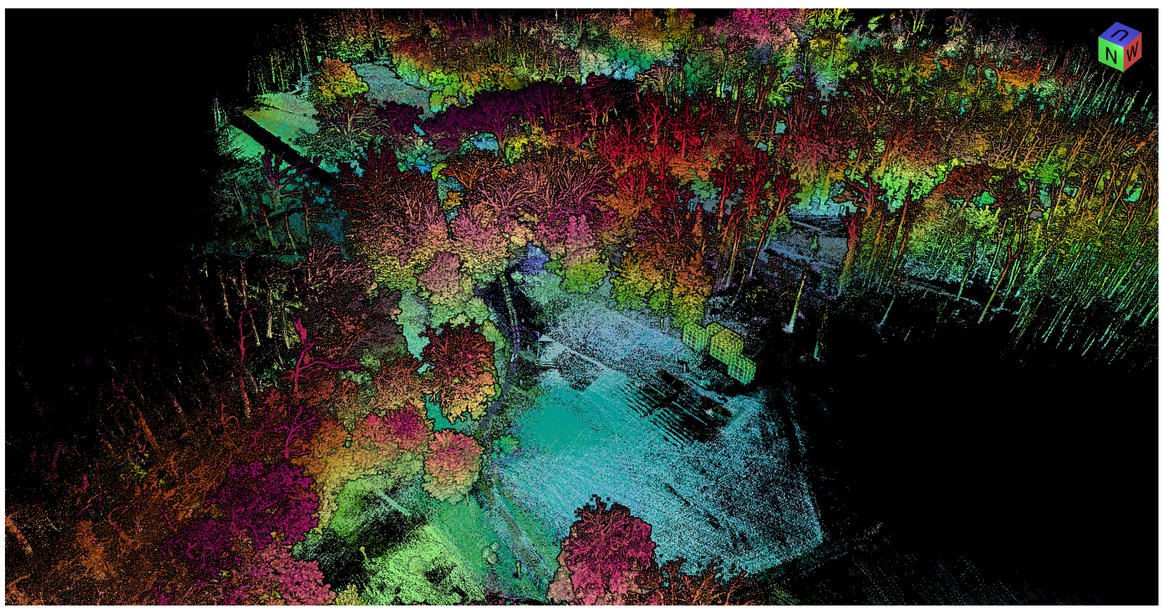
1. Introduction

Machine perception is an integral part in a wide variety of robotics and environment surveying applications. The focus of this work is advancing the state of the art **in Lidar Simultaneous Localization and Mapping (SLAM) based on submaps and pose graph optimisation.**

2. Problem Description

Herein we exploit some properties of *submaps,* a form of spatio-temporal segmentation of the observed environment, in order to make the following tractable on a **commodity laptop**:

- Forming a full pose graph-based 3D lidar SLAM stack capable of processing **extensive (multi-hour)** datasets and delivering **survey-grade** point cloud assets
- Wide-area, high frequency **frontier detection** in 2D lidar SLAM as part of **an autonomous robot exploration system**

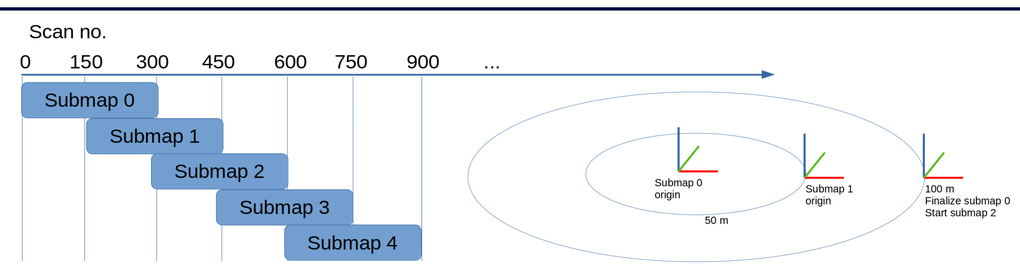


Maksimir forest, 30 minute on-foot survey, Velodyne VLP-16, 2019. Processes in ~10 minutes on a commodity laptop.

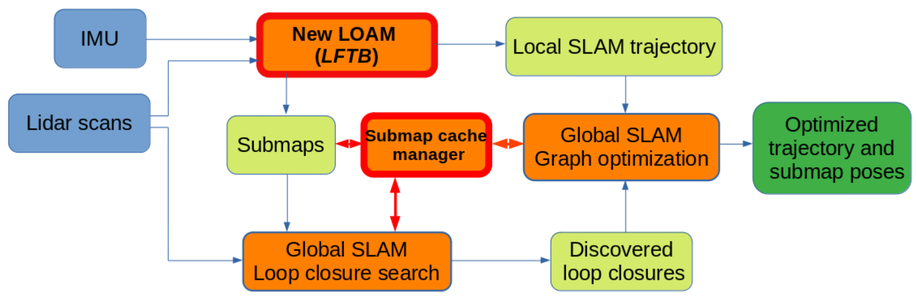
Austin, Texas. 4.3 km loop, Hesai Pandar XT32M1, 2021. Faux coloring indicates different submaps. Drift without loop closure: ~3-4 meters. Realtime factor: ~1

3. Methodology and Results

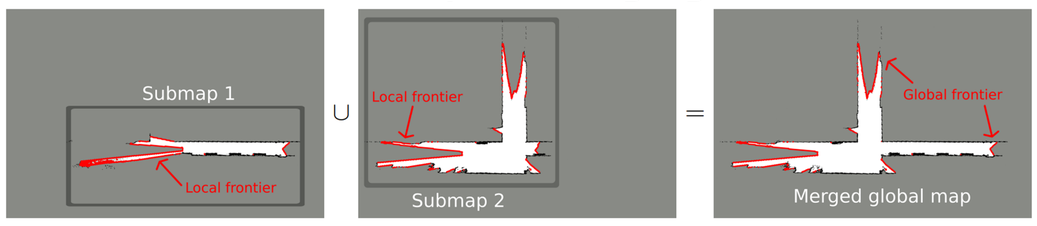
- **New SLAM frontend, *LFTB,*** derived from LOAM (Zhang 2014)
- Loop-closing using the temporal occupancy grid submaps-based backend from Cartographer (Hess 2016); **offloading submaps to disk** based on least-recently used (LRU) pruning between loop closure search epochs for improved scalability
- Making LFTB scalable by introducing range-based submaps (in contrast to temporal-based submaps from Cartographer)
- Voxel grid hashmap-based submaps which vastly simplify the frontend pipeline compared to LOAM, reducing it **solely to the mapping stage**, which runs at 1-5x realtime (**~100x increase** in performance of the mapping stage compared to LOAM)
- Exploiting the interaction between pose graph optimization and how submaps move for providing high-frequency frontier updates in 2D lidar exploration (~80 Hz on the large-scale Deutsches museum dataset, with the algorithm complexity dependent on the frontier **perimeter**, not **area**) [1]



Temporal submaps (Cartographer) vs. motion range-based (LFTB)



Architecture of the new 3D SLAM stack, with the new components highlighted in red.



The method of computing fast 2D frontier updates using the concept of *local frontiers* of each submap, which are subject to *stabbing queries* of occupancy in other overlapping submaps [1]

Croatian National Theatre (HNK) on-foot survey, Hesai Pandar XT32M1, 2023.

4. Conclusion

We have demonstrated a performant submap and pose graph-based optimization 3D SLAM stack which can fuse survey-grade point clouds, as well as a 2D frontier detection method viable for use in an autonomous environment exploration system.

Acknowledgments

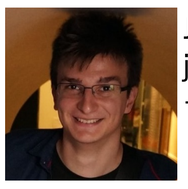
Thanks to Phoenix Lidar Systems for the partnership in the development of the 3D SLAM stack and providing long-term evaluation of its performance in commercial conditions.

PHOENIX LiDAR SYSTEMS

References

[1] Oršulić, Miklić, Kovačić: Efficient Dense Frontier Detection for 2D Graph SLAM Based on Occupancy Grid Submaps; // IEEE Robotics and Automation Letters, 4 (2019)

Contact



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PhD Day Faculty of Electrical Engineering and Computing, 1 June 2023