

Efficient and Accurate 3D Reconstruction Based on LiDAR Bundle Adjustment

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I. INTRODUCTION

This report provides an overview of our system used to complete the HILTI 2023 SLAM Challenge. The system is built based on our previous works: FAST-LIO2 [1], VoxelMap [2], BALM2-LIO [3], and a global LiDAR bundle adjustment (HBA [4]). Author names are listed in order of contribution to this work.

II. PIPELINE

Our approach uses the data from LiDAR (Hesai PandarXT-32, Robosense BPearl) and IMU (Alphasense, Xsens MTi-670) only. Both LiDARs have large FoVs and dense measurements which are very suitable for construction environments. Our front-end algorithms are robust in aggressive, degenerated scenarios, and are able to run in real-time on a standard desktop computer. The pipeline of our framework is shown in Fig. 1 below. The IMU and LiDAR data are fed into a filter-based (VoxelMap [2]) or optimization-based (BALM2-LIO [3]) front end. The front end efficiently and robustly produces the odometry and undistorted LiDAR point clouds. These two outputs are then fed into the BA-based back end (HBA [4]) to globally optimize the sensor poses. Even though no loop closure module is used, the initial odometry estimated by our front end is good enough for our back-end optimization.

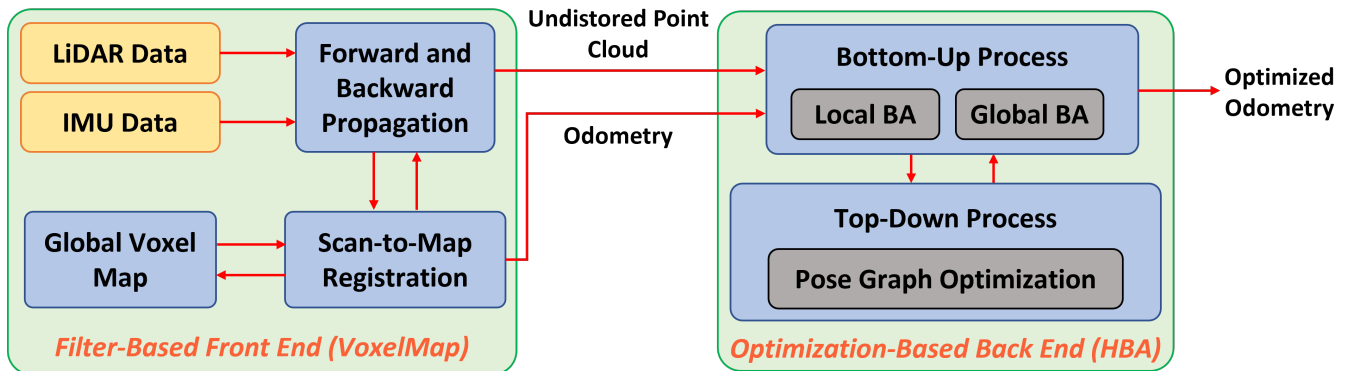


Figure 1: Our proposed pipeline.

III. RESULTS

All the sequences are processed in a computer with an Intel i7-9700K 8-Core CPU and 64 GiB RAM using the same parameters. The averaged processing time and accuracy of each sequence are shown in Table I and Table II below. It should be noted that the processing time of the front end is the time per scan while that of the back end is the time per iteration. Here only shows the mapping result of sequences *Site1_Handheld1* (see Fig. 2), *Site2_Robot1* (see Fig. 3), and *Site3_Handheld2* (see Fig. 4).

Table I: Averaged Processing Time (s) on HILTI 2023 Dataset

Process Time	S1_H1	S1_H2	S1_H3	S1_H4	S1_H5	S2_R1	S2_R2	S2_R3	S3_H1	S3_H2	S3_H3	S3_H4
Front End (s)	0.049	0.056	0.044	0.037	0.036	0.041	0.048	0.046	0.038	0.031	0.037	0.032
Back End (s)	99.084	68.061	55.913	46.665	44.054	242.333	120.740	129.993	21.559	12.191	34.194	14.971

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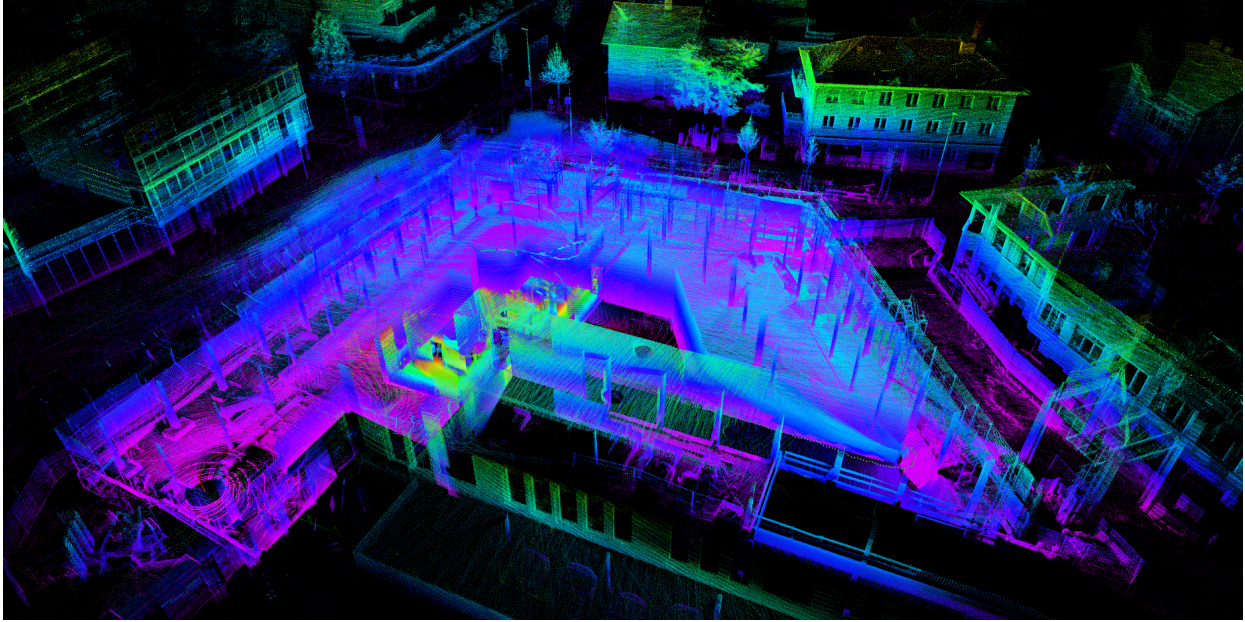


Figure 2: Mapping result of *Site1_Handheld1*.

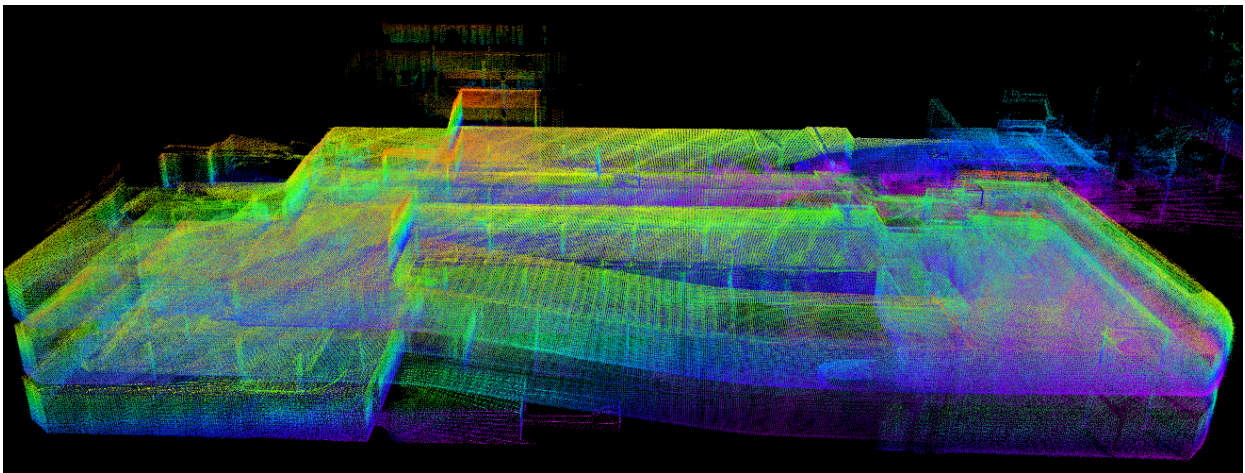


Figure 3: Mapping result of *Site2_Robot1*.

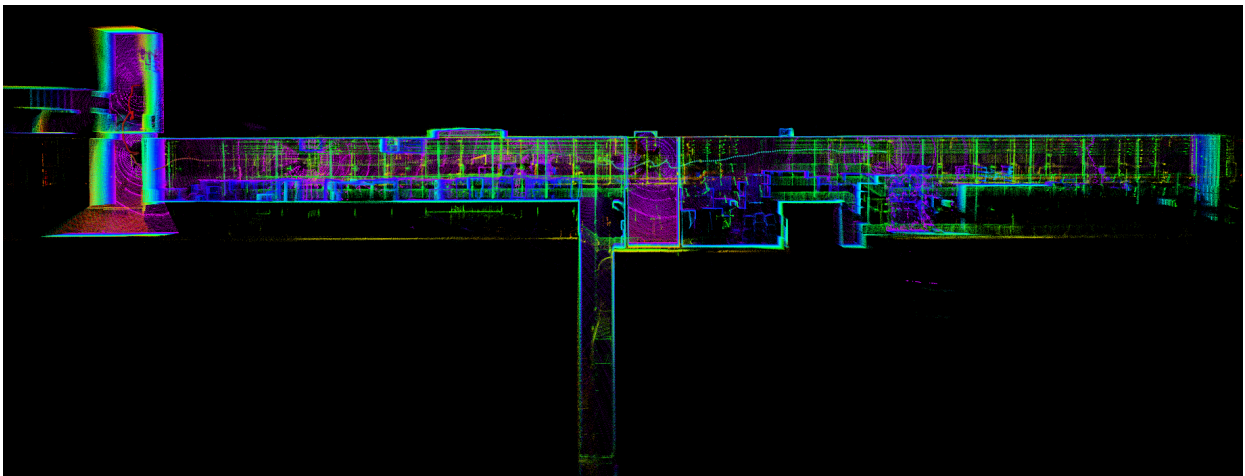


Figure 4: Mapping result of *Site3_Handheld2*.

Table II: APE (m) on HILTI 2023 Dataset

APE (m)	S1_H1	S1_H2	S1_H3	S1_H4	S1_H5	S2_R1	S2_R2	S2_R3
RMSE	0.010	0.007	0.006	0.009	0.004	0.122	0.046	0.042
Min	0.002	0.002	0.003	0.008	0.001	0.062	0.006	0.002
Max	0.015	0.011	0.009	0.009	0.006	0.162	0.059	0.060

S stands for *Site*, H stands for *Handheld* and R stands for *Robot*.

IV. CONCLUSION

The proposed framework works efficiently and is robust in every sequence. However, the computation time of the global bundle adjustment method could still be improved.

REFERENCES

- [1] W. Xu, Y. Cai, D. He, J. Lin, and F. Zhang. Fast-lio2: Fast direct lidar-inertial odometry. *IEEE Transactions on Robotics*, 38(4):2053–2073, 2022.
- [2] C. Yuan, W. Xu, X. Liu, X. Hong, and F. Zhang. Efficient and probabilistic adaptive voxel mapping for accurate online lidar odometry. *IEEE Robotics and Automation Letters*, 7(3):8518–8525, 2022.
- [3] Z. Liu, X. Liu, and F. Zhang. Efficient and consistent bundle adjustment on lidar point clouds, 2022. doi:10.48550/arXiv.2209.08854.
- [4] X. Liu, Z. Liu, F. Kong, and F. Zhang. Large-scale lidar consistent mapping using hierarchical lidar bundle adjustment. *IEEE Robotics and Automation Letters*, 8(3):1523–1530, 2023.