Point-wise LiDAR-Inertial Odometry with Pose Graph Optimization in HILTI SLAM Challenge 2023

Hyunjae Gil[1*], Wooseong Yang[1*], Dongjae Lee[1*], Minwoo Jung[1*] and Ayoung Kim[1*]

Abstract— **This work proposes a method to obtain more accurate odometry results for the HILTI SLAM Challenge Dataset 2023. Our approach involves utilizing a point-wise Light Detection and Ranging (LiDAR) inertial odometry system and pose graph optimization. For point-wise LiDAR inertial odometry, we use Point-LIO, which is capable of dealing with extremely aggressive motions typically observed in fast-moving drones or heavily shaking handheld devices by modeling the inertial measurement unit (IMU) measurement as output and updating the state at each LiDAR point measurement. Although LiDAR inertial odometry alone can produce relatively good results, combining it with pose graph optimization is a promising solution for achieving more precise odometry of the robot. Therefore, we construct a pose graph from the results of LiDAR inertial odometry and loop closures to optimize the global pose, resulting in improved odometry. Our proposed method is expected to enhance the performance of SLAM systems in challenging environments such as construction sites, which have become increasingly important in robotics applications.**

I. INTRODUCTION

This report presents a detailed description of our approach and experimental results using the HILTI SLAM Challenge Dataset 2023. Our odometry method, employed for this challenge, relies solely on LiDAR and IMU sensor data and is not real-time, prioritizing higher accuracy. Our focus was on designing a SLAM system capable of robustly handling aggressive motions, including running with a handheld system, and rapid rotations, as well as addressing apparent motion caused by actions such as opening doors and drawing curtains.

II. METHOD

The SLAM system we used for the challenge consists of two modules: point-wise LiDAR-inertial odometry and pose graph optimization.

A. Point-wise LiDAR-inertial odometry

Point-LIO[1] utilizes sequentially sampled LiDAR point measurements and IMU data for state updates. The system propagates the state using the IMU data and an IMU measurement model until the arrival of the next LiDAR point, at which point the corresponding plane in the map is searched, and the state is updated using the point-to-plane measurement model. This approach enables high-frequency odometry estimation and robustness against motion distortion through point-wise updates.

While the original Point-LIO method demonstrates excellent performance, it employs a fixed iteration of one for state updates, emphasizing real-time odometry. To enhance accuracy, a trade-off was made by sacrificing real-time performance. An adaptive iteration scheme was implemented for the measurement model, adjusting the number of iterations to maintain the residual below a specific threshold. Furthermore, to address the limitations of the point-wise measurement model in degenerate environments, a scan-wise measurement model was incorporated. Following the point-wise state update process, a scan-wise state update step was introduced to obtain more precise odometry results. These modifications were specifically tailored to improve the accuracy of the odometry system in challenging scenarios.

B. Pose Graph Optimization

To address the issue of accumulated errors in odometry results obtained due to the local drift of Point-LIO, we incorporated pose graph optimization techniques. The objective was to minimize global errors and optimize the odometry estimation process. When loops were detected, pose graph optimization was performed to refine all poses within the graph. For loop detection, we employed the Generalized Iterative Closest Point[2] (GICP) algorithm. To perform graph optimization, we leveraged the GTSAM[3] library, which integrates the iSAM (incremental Smoothing and Mapping) algorithm.

III. RESULTS

The results are summarized in Table 1, demonstrating that our proposed method achieved fairly accurate odometry results. (Note that different sets of parameters were used for each sequence.) The results were obtained on an Intel Core i7-12700 CPU with 64GiB RAM. The mapping results obtained through the odometry can also be observed in Figures 1, 2 and 3. Table 2 presents the average processing time of our system for each LiDAR scan. This indicates that our system operates at nearly real-time performance, ranging from 3 to 10 Hz, depending on the parameters.

IV. CONCLUSION

In this work, we have presented a method to improve the accuracy of odometry results for the HILTI SLAM Challenge Dataset 2023. Our approach combines a point-wise LiDAR inertial odometry system, specifically Point-LIO, with pose graph optimization to achieve more precise odometry estimates for robots operating in challenging environments.

---

[*] All authors equally contributed to this submission.

[1] H. Gil, W. Yang, D. Lee, M. Jung and A. Kim are with the Dept. of Mechanical Engineering, SNU, Seoul, S. Korea `[h.gil, yellowish, pur22, moonshot, ayoungk]@snu.ac.kr`

TABLE I: The final results of the HILTI SLAM Challenge 2023

	<0.5cm	<1cm	<3cm	<6cm	<10cm	<40cm	>40cm	Score
site1_handheld_1	2.00	1.00	1.00	0.00	0.00	0.00	0.00	70.00
site1_handheld_2	1.00	2.00	1.00	0.00	0.00	0.00	0.00	57.50
site1_handheld_3	0.00	2.00	2.00	0.00	0.00	0.00	0.00	40.00
site1_handheld_4	1.00	0.00	0.00	2.00	0.00	0.00	0.00	50.00
site1_handheld_5	2.00	1.00	0.00	0.00	0.00	0.00	0.00	83.33
site2_robot_1	0.00	0.00	0.00	0.00	0.00	3.00	4.00	2.14
site2_robot_2	1.00	1.00	1.00	0.00	0.00	0.00	0.00	60.00
site2_robot_3	1.00	0.00	4.00	0.00	0.00	0.00	0.00	44.00
site3_handheld_1	3.00	0.00	0.00	0.00	0.00	0.00	0.00	125.00
site3_handheld_2	0.00	2.00	2.00	2.00	0.00	0.00	0.00	70.00
site3_handheld_3	0.00	1.00	3.00	3.00	1.00	0.00	0.00	57.50
site3_handheld_4	1.00	1.00	2.00	0.00	0.00	0.00	0.00	105.00
Total	12.00	11.00	16.00	7.00	1.00	3.00	4.00	789.48

TABLE II: Average processing time of our system for each LiDAR scan

	Processing Time
site1_handheld_1	0.21261s
site1_handheld_2	0.14499s
site1_handheld_3	0.15617s
site1_handheld_4	0.07764s
site1_handheld_5	0.16067s
site2_robot_1	0.24598s
site2_robot_2	0.28506s
site2_robot_3	0.21147s
site3_handheld_1	0.26355s
site3_handheld_2	0.10772s
site3_handheld_3	0.11177s
site3_handheld_4	0.16531s

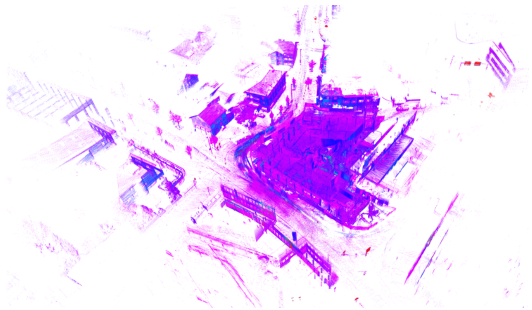

Fig. 1: Visualized mapping results for the first sequence of site 1 in the 2023 Dataset

The application of our proposed method in challenging environments, such as construction sites, holds great potential for enhancing the performance of SLAM systems. The improved odometry accuracy can enable robots to navigate and map these complex environments more effectively, thereby contributing to the advancement of robotics applications.

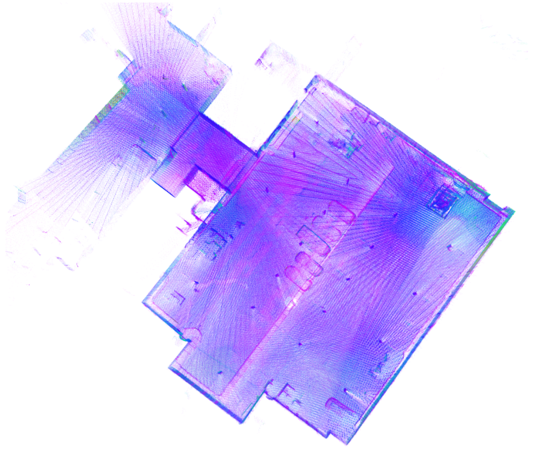

Fig. 2: Visualized mapping results for the second sequence of site 2 in the 2023 Dataset

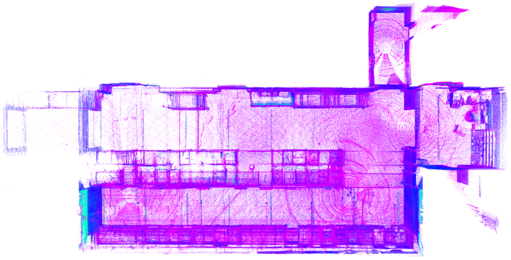

Fig. 3: Visualized mapping results for the first sequence of site 3 in the 2023 Dataset

REFERENCES

[1] D. He, W. Xu, N. Chen, F. Kong, C. Yuan, and F. Zhang, “Point-lio: Robust high-bandwidth light detection and ranging inertial odometry,” *Advanced Intelligent Systems*, vol. n/a, no. n/a, p. 2200459. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/aisy.202200459

[2] A. Segal, D. Hähnel, and S. Thrun, “Generalized-icp,” 06 2009.

[3] F. Dellaert and G. Contributors, “borglab/gtsam,” May 2022. [Online]. Available: https://github.com/borglab/gtsam)