Towards Effective LiDAR-Based Mapping with Handheld Rotating Sensors in Complex Environments

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Abstract: Mobile LiDAR systems facilitate 3D mapping in complex environments featuring varied terrain and structures. To address the limited field of view of compact LiDAR sensors, mechanical rotation can be employed to extend spatial coverage. However, this method results in sparse point distributions and decreased frame-to-frame overlap, presenting significant challenges for conventional SLAM algorithms in achieving reliable scan matching and consistent mapping. This study investigates SLAM performance under these conditions through experiments using a manually rotated Velodyne VLP-16 sensor. Data were collected along a trajectory combining outdoor building perimeters and indoor corridors, relying solely on LiDAR without GPS, IMU, or camera assistance. Preliminary tests with HDL-Graph-SLAM diverged under the sparse, low-overlap conditions, whereas KISS-ICP provided stable odometry with residual drift. Building on this, KISS-SLAM was analyzed in detail by tuning parameters such as max_range, voxel_size, and local map resolution. Results show that reducing max_range to 20 m improved odometry stability in narrow indoor spaces and adjusting voxel_size to approximately 0.01 × max_range yielded generally consistent performance. Loop closure detection was highly sensitive to local map resolution: default settings failed to recognize revisits, whereas tuned parameters substantially increased loop closure detections, effectively reducing drift and improving global consistency. While finer local map resolution improves mapping accuracy, it also increases computational cost, underscoring the importance of selecting parameters that balance accuracy with efficiency. These findings highlight adaptive strategies for handling sparse and irregularly sampled point clouds, demonstrating that compact rotating LiDAR systems are feasible for LiDAR-only mapping in GPS-denied environments, as long as parameter settings are carefully tuned to balance accuracy with computational efficiency.

Keywords: handheld LiDAR, rotating sensor, SLAM

1. Introduction

Compact LiDAR sensors are increasingly employed for mobile mapping; however, their narrow field of view (FoV) limits spatial coverage in complex environments. Mechanical rotation provides a cost-effective method to extend coverage, but it results in sparse point distributions and low overlap between consecutive scans. These factors pose challenges for SLAM algorithms, affecting odometry reliability and loop closure. This study addresses these challenges by analyzing the performance of SLAM algorithms using rotating LiDAR data and investigating how parameter tuning can enhance mapping quality in mixed indoor–outdoor environments.

2. Methodology

Experiments were conducted using a Velodyne VLP-16 LiDAR sensor mounted on a handheld rotating platform. The system included an onboard computing module and independent battery power supply, enabling LiDAR-only data collection without GPS, IMU, or camera support (Figure 1). The trajectory consisted of circling a building exterior and traversing indoor corridors and classrooms before revisiting the starting location to enable loop closure opportunities.

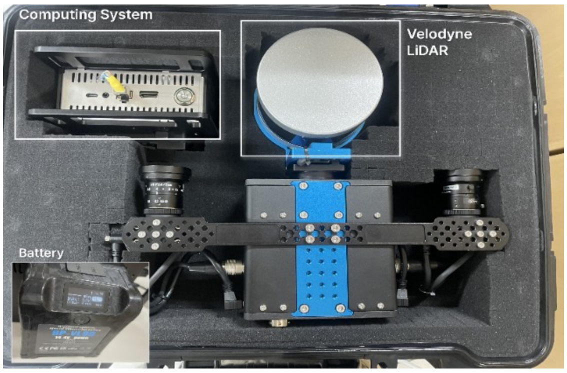


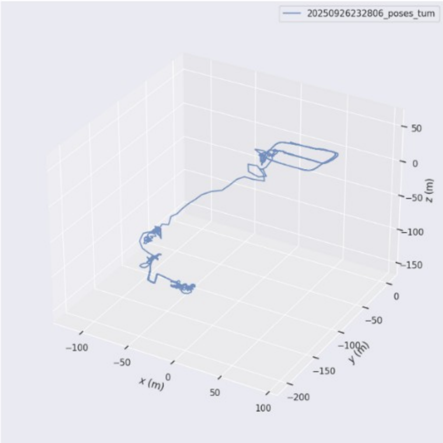
Figure 1: Handheld rotating LiDAR sensor system configuration.

Preliminary tests with HDL-Graph-SLAM revealed divergence due to the sparse data and low overlap characteristics of rotating LiDAR. To evaluate odometry performance, KISS-ICP was applied, followed by a detailed analysis of KISS-SLAM. The parameters varied included max_range, voxel_size, local map distance, density_map_resolution, density_threshold, and hamming_distance_threshold. Performance was assessed based on trajectory consistency, visual inspection of point cloud integration, and the frequency of loop closure detection.

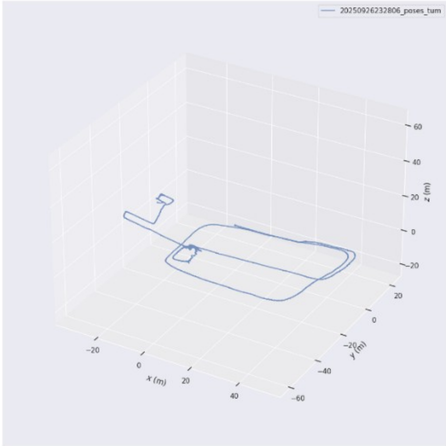
3. Results

a. Odometry Performance

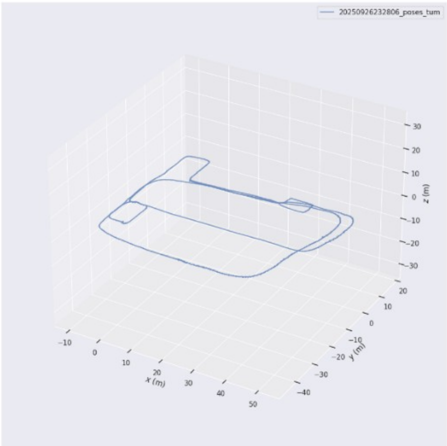
KISS-ICP results revealed that the default max_range (100 m) led to divergence indoors, while reducing max_range to 20 m significantly improved odometry stability (Figure 2). Excessively small ranges (e.g., 10 m) degraded outdoor alignment, confirming that environment-specific tuning is essential. Setting voxel_size to about 0.01 × max_range provided stable odometry across different environments.



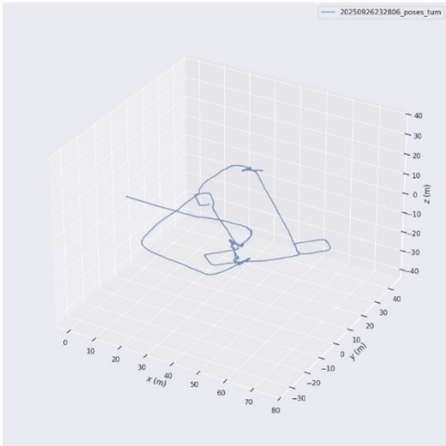
100 m (default)



50 m



20 m

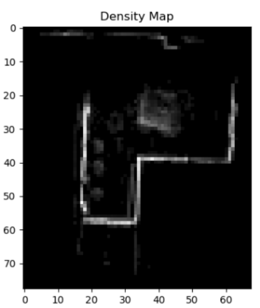


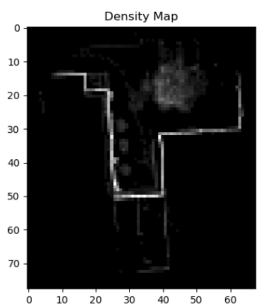
10 m

Figure 2: Trajectory comparison of KISS-ICP under different max_range settings. The default 100 m range diverged indoors, while reducing to 20 produced more stable trajectories.

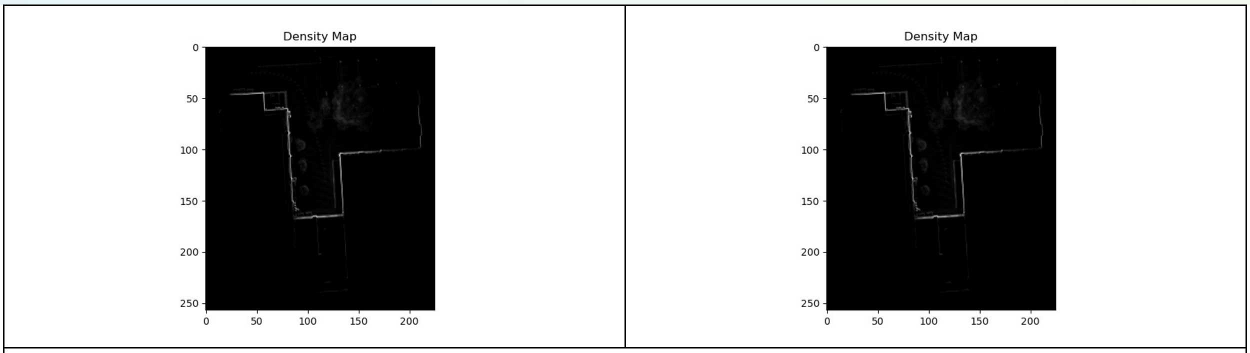
b. Loop Closure and Global Consistency

With KISS-SLAM, loop closure detection strongly depended on local map resolution. Under default settings (density_map_resolution=0.5, density_threshold=0.05), revisited areas were often undetected, and loop closures rarely occurred. After lowering density_map_resolution to 0.15 and jointly adjusting density_threshold and hamming_distance_threshold, loop closure frequency increased substantially, effectively reducing drift and improving global map consistency (Figure 3).





Default settings



Tuned settings

Figure 3: Effect of local map resolution on loop closure detection and global map consistency. Default settings (top) failed to detect revisits, while tuned settings (bottom) enabled successful loop closure and consistent integration.

c. Parameter Summary

A summary of key parameter settings and their qualitative performance is provided in Table 1. In addition to the summarized performance metrics, Figure 4 presents the final integrated point cloud results, clearly demonstrating how parameter tuning enhances both global consistency and map completeness

Table 1: Qualitative outcomes of odometry stability, loop closure, and map consistency under default and tuned parameter settings.

Setting	max_range	voxel_size	Local map resolution	Odometry stability	Loop closure	Map consistency
Default	100 m	0.5	0.5	Unstable indoors	Not detected	Divergence
Tuned	20 m	0.2	0.15	Stable indoors/outdoors	Frequent, reliable	Consistent

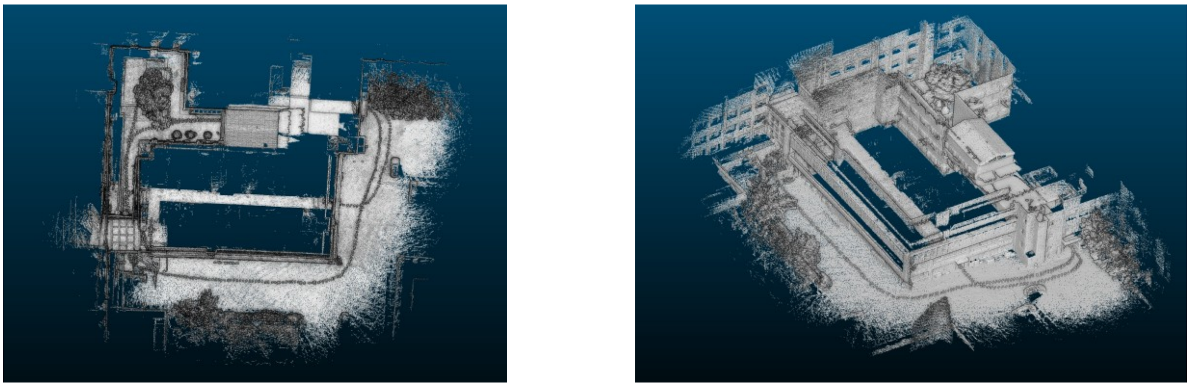


Figure 4: Final point cloud integration results with tuned parameters. Left: top-down view. Right: oblique perspective view.

4. Conclusion

This study evaluated SLAM performance using rotating LiDAR data, with a focus on parameter tuning for odometry and loop closure. Reducing the max_range parameter improved odometry accuracy in confined indoor spaces, while setting the voxel_size to approximately 0.01 times the max_range provided overall stability. Loop closure reliability was enhanced by decreasing the local map resolution, although this resulted in increased computational demand.

The findings demonstrate that parameter tuning is essential for achieving robust LiDAR-only mapping under sparse and low-overlap conditions. Compact rotating LiDAR systems can provide consistent 3D mapping in GPS-denied environments, provided that parameter selections are adapted to the environmental context and computational constraints. Future research will include quantitative validation and benchmarking against state-of-the-art algorithms such as CT-ICP and LeGO-LOAM.

References

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