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Accuracy Verification Methodology of Water borne LiDAR-SLAM using CLAS Positioning

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ABSTRACT: Many autonomous boats use global navigation satellite system (GNSS) positioning for self-positioning and navigation. Moreover, point clouds can be acquired with laser scanning and real-time kinematic-GNSS (RTK-GNSS) positioning. However, in dense urban areas, the GNSS positioning environment is poor because rivers are surrounded by many bridges, buildings, and other structures. Therefore, we focus on the LiDAR-based simultaneous localization and mapping (LiDAR-SLAM) positioning methodology to achieve positioning in poor GNSS positioning environments. However, the accuracy of LiDAR-SLAM is not easy to evaluate because high-precision 3D maps and reference point networks have not been sufficiently prepared in urban rivers. Therefore, in this study, we proposed an accuracy verification methodology for LiDAR-SLAM in urban rivers. The accuracy verification was performed as follows. First, the corresponding section was extracted from position data estimated with LiDAR-SLAM and RTK-FIX position data obtained with CLAS. Next, all LiDAR points were matched with the normal distribution transform scan matching. Then, we evaluated accumulated errors in the LiDAR-SLAM result using the corresponding points in the CLAS positioning data. Through our experiment, we confirmed that our methodology can verify the accuracy of LiDAR-SLAM with the CLAS.

1. INTRODUCTION

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism is promoting mobility as a service (MaaS) to solve various transportation service issues in cities. MaaS has been implemented to improve the convenience of transportation and solve regional issues. In Tokyo, as a part of MaaS, we can focus on autonomous boats as a new transportation service system to support existing public transportation services such as railroads.
Many ships and boats use GNSS positioning data as the main data for positioning and navigation. However, in urban rivers, poor GNSS positioning environments exist because of obstacles such as buildings and bridges. Therefore, the authors focus on simultaneous positioning and mapping (SLAM) processing using LiDAR to cover positioning in poor GNSS environments. In our previous studies, we have confirmed that LiDAR-SLAM can reconstruct 3D scans from a point cloud boat in urban rivers (Kimura et al., 2021). Then we found the necessity to develop a methodology to verify the accuracy of LiDAR-SLAM in urban rivers, because no reference points or 3D maps of urban rivers exist with high accuracy on rivers. Therefore, we proposed a methodology to evaluate the accuracy of positioning estimated with LiDAR-SLAM using centimeter level augmentation service (CLAS) positioning results.

2. METHODOLOGY

The proposed methodology evaluated LiDAR-SLAM result using CLAS positioning data. First, we estimate point clouds and sensor positioning based on LiDAR-SLAM with local coordinate values. In this research, we applied the normal distribution transform (NDT) as the SLAM processing. Second, the estimated positions are compared with CLAS data.

2.1 NDT scan matching

The SLAM is based on point-matching processing such as scan-matching methodologies. Two main types of scan matching methodologies exist: the iterative closest point (ICP) and NDT(Biber et al., 2003). The ICP matches the reference data and input data based on the estimation of the shortest distance between the corresponding points. First point clouds of reference data are divided into cells or voxels. Next, matched points are estimated on cells or voxels. NDT scan matching has the advantage of scalability in point cloud processing.

2.2 Error evaluation based on open traverse

The estimated positions are compared with CLAS data to evaluate errors based on an open traverse. Traverse surveying consists of closed traverse and open traverse Closed traverse is a surveying methodology to adjust for errors using gaps of the start and end reference points based on loop closure. Open traverse is a methodology using reference points along a line.

Closed traverse is a basic idea to adjust for errors in SLAM. However, a path distortion problem occurs because of the long measurement path in the 3D measurement of the river. Thus, we focus on open traverse with continuous CLAS positioning data as reference points located on a line.

Figure 1 shows the accuracy verification methodology of LiDAR-SLAM. First, synchronized LiDAR and CLAS data are acquired. In this step, CLAS positioning data are classified into FIX and non-FIX solutions. Second, SLAM is applied to estimate sensor positions and point clouds. Third, a local trajectory is extracted from SLAM and CLAS data. Fourth, the coordinate system of CLAS data is transformed from WGS 84 to a local coordinate system for data corresponding between SLAM and CLAS data. Finally, errors of all positions from the start to the end point are evaluated.

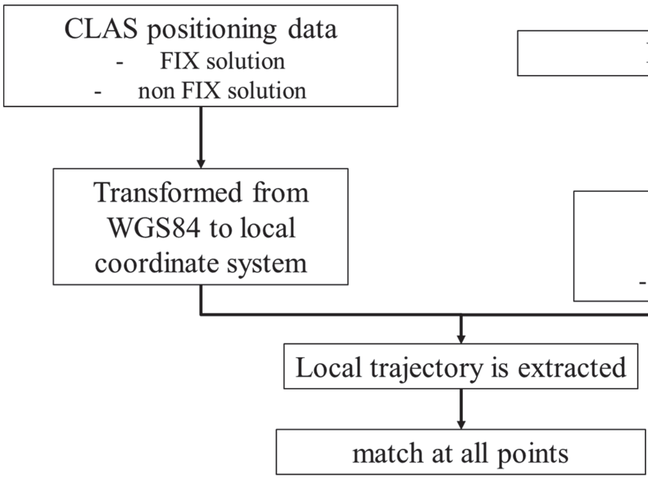


Figure 1. Proposed methodology

3. EXPERIMENTS

We selected the Kanda River (between the Suidobashi to Asakusabashi bridge), as shown in Figure 2, as our study area consisted of GNSS (Figure 3) and non-GNSS environments (Figure 4). The measurement period was 9:00-12:30 on December 3, 2021, when the tide level in Tokyo Bay was low. The PPP-RTK data were acquired using a GNSS antenna (GPS- 703-GGG-HV, NovAtel) and two types of GNSS modules: AsteRx4 (Septentrio) and mosaic-X5 (Septentrio). The positioning data were acquired at 5 Hz. The point clouds were acquired at 10 Hz using VLP-32C (Velodyne) and downsampled to 5-Hz data.

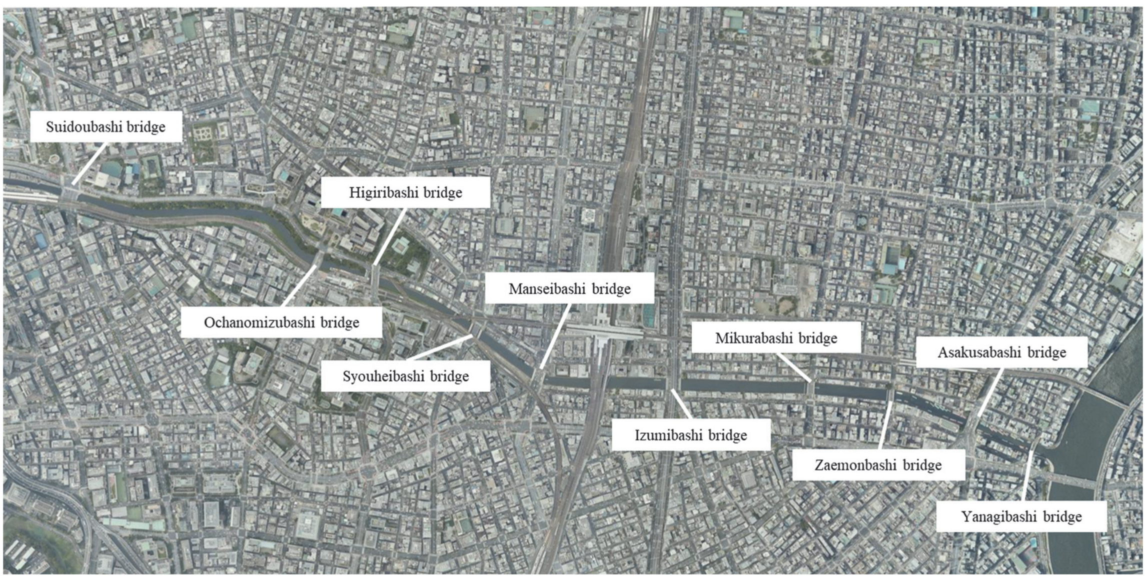


Figure 2. Study area

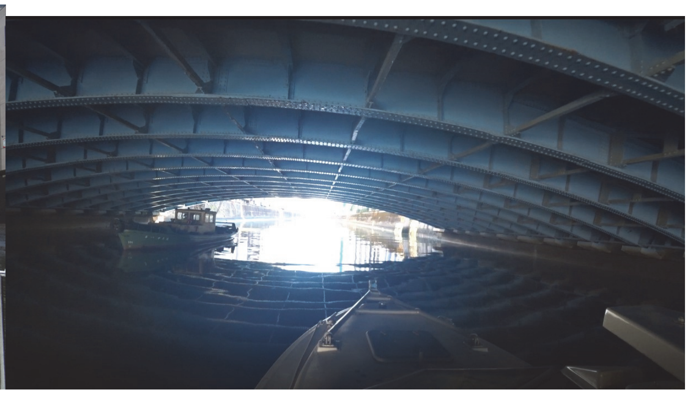


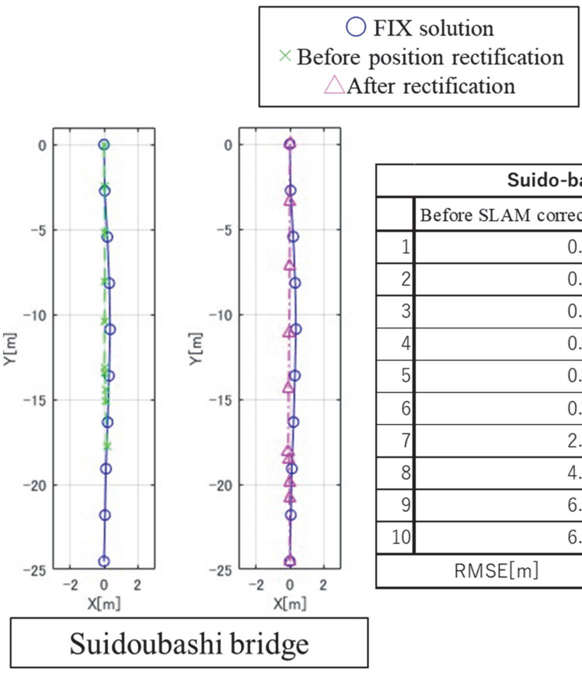
Figure 3. GNSS environment (Izumibashi bridge) Figure 4 . Non-GNSS environment (Izumibashi bridge)

4. RESULTS

The relative accuracy verification of SLAM results is described with GNSS positioning data as follows.

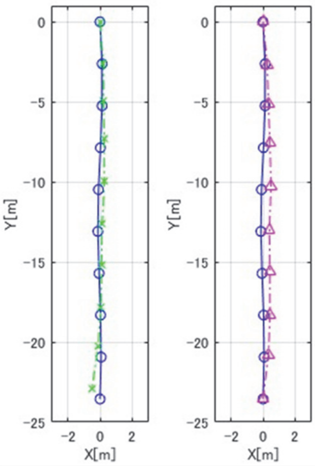
4.1 Points at which consecutive FIX solutions were obtained

The estimated results with the NDT scan matching at the sample 10 points where FIX solutions were obtained continuously (Suidobashi Ochanomizubashi, and Manseibashi bridges). All estimated positions were, rectified using the corresponding points of CLAS positioning results.
The blue line shows the CLAS positioning result with the FIX solution, the green line shows the SLAM result before position rectification, and the pink line shows the SLAM result after rectification. The relative errors at each position were estimated as 3.557 [m] (RMSE) at the Suidobashi bridge, 0.294 [m] (RMSE) at the Ochanomizubashi bridge, and 0.251 [m] (RMSE) at the Manseibashi bridge.



Suido-bashi bridge		
	Before SLAM correction	After SLAM correction
1	0.000	0.000
2	0.266	0.669
3	0.287	1.745
4	0.294	2.984
5	0.570	3.512
6	0.572	4.484
7	2.874	2.246
8	4.649	0.825
9	6.708	0.996
10	6.738	0.000
RMSE[m]		3.557

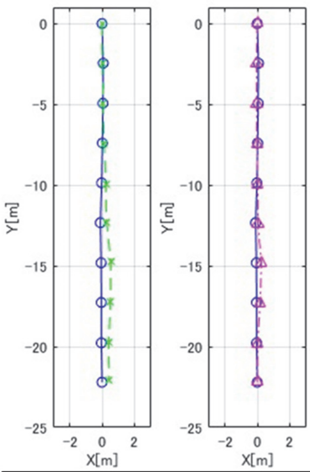
Figure 5. Estimated relative errors (Suidoubashi bridge)



Ochanomizu-bashi bridge		
	Before SLAM correction	After SLAM correction
1	0.000	0.000
2	0.079	0.137
3	0.286	0.238
4	0.598	0.526
5	0.634	0.634
6	0.534	0.551
7	0.584	0.511
8	0.512	0.408
9	0.702	0.286
10	0.816	0.000
RMSE[m]		0.294

Ochanomizubashi bridge

Figure 6. Estimated relative errors (Ochanomizubashi bridge)



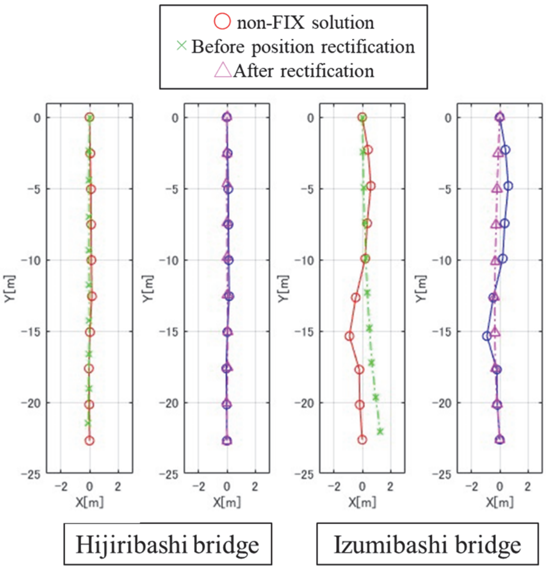
Mansei-bashi bridge		
	Before SLAM correction	After SLAM correction
1	0.000	0.000
2	0.069	0.120
3	0.034	0.106
4	0.131	0.111
5	0.270	0.160
6	0.386	0.152
7	0.611	0.311
8	0.566	0.224
9	0.463	0.089
10	0.456	0.000
RMSE[m]		0.251

Manseibashi bridge

Figure 7. Estimated relative errors (Manseibashi bridge)

4.2 Poor GNSS positioning environments

Figure 10 shows the estimated result of accumulated errors in LiDAR-SLAM in poor GNSS positioning environments (Hijiribashi and Izumibashi bridge). The red line shows the CLAS positioning results with the non-FIX solution, the green line shows the SLAM positioning results before the error adjustment, and the pink line shows the SLAM results after the error adjustment.



	Hijiri-bashi bridge		Izumi-bashi bridge	
	Before SLAM correction	After SLAM correction	Before SLAM correction	After SLAM correction
1	0.000	0.000	0.000	0.000
2	0.149	0.063	0.629	0.598
3	0.652	0.405	0.696	0.642
4	0.556	0.176	0.676	0.604
5	0.732	0.226	0.613	0.508
6	0.786	0.163	0.568	0.384
7	0.835	0.033	0.570	0.243
8	0.998	0.101	0.589	0.176
9	1.151	0.074	0.583	0.090
10	1.219	0.000	0.563	0.000
RMSE[m]		0.704	RMSE[m]	0.298

Figure 10. Estimated relative errors (Hijiribashi bridge and Izumibashi bridge)

5. DISCUSSION

In this paper, the CLAS positioning data were assumed as the true value, and the SLAM result was corrected using the residual errors between the positions estimated from the LiDAR-SLAM and CLAS positioning results. Based on the results of the Manseibashi bridge 0.251 [m] (RMSE) and the Ochanomizubashi bridge 0.294[m](RMSE), we confirmed that the CLAS results can be used to evaluate the accuracy of positions estimated from SLAM, the section of GNSS positioning results for which a FIX solution was obtained. We also confirmed that CLAS positioning results can be used to evaluate the accuracy of failed SLAM positioning results such as the Suidobashi bridge 3.557[m](RMSE) because of monotonous geometrical features for the point cloud matching shown in Figure 9.

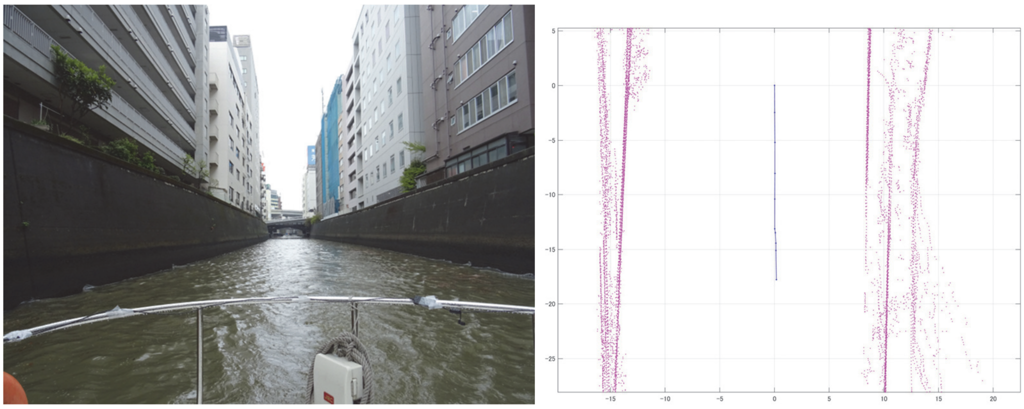


Figure 9. Failed result in SLAM (left image: photo of the Suidobashi bridge, right image: estimated positions and integrated point clouds)

6. CONCLUSION

We proposed a methodology to verify the accuracy of positions estimated from LiDAR-SLAM in an urban river. Through experiments on the Kanda River (between the Suidobashi and Asakusabashi bridges), we confirmed that CLAS positioning results with continuous FIX solution can be used to verify the accuracy of LiDAR-SLAM. In this study, accumulated errors were corrected by error adjustment based on open traverse using CLAS data as the true values. Alternatively, in poor GNSS positioning environments, such as under bridges and roads, the proposed methodology cannot easily perform the accuracy verification. Therefore, other methodology in non-GNSS environments are investigated in future works.

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