URBAN RIVER MAPPING BY BOAT-BASED MOBILE LASER SCANNING WITH PPP-RTK

Kimura Naoto [1], Masafumi Nakagawa [1], Koki Kurita [1],
Tomohiro Ozeki [2], Nobuaki Kubo [2], Etsuro Shimizu [2], Ryosuke Shibasaki [3]
[1]Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, Tokyo 135-8548, Japan
[2]Tokyo University of Marine Science and Technology, 2-1-6, Etchuujima, Koto-ku, Tokyo 135-8533, Japan
[3]The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8654, Japan
Email: ah18027@shibaura-it.ac.jp; mnaka@shibaura-it.ac.jp

KEY WORDS: 3D mapping, PPP-RTK, SLAM, Indoor-outdoor seamless positioning, Mobile Laser Scanning

ABSTRACT: In recent years, Mobility as a Service (MaaS) has been discussed to provide new transportation technology services with GIS, IoT, and automated driving technology. In waterfront areas, autonomous water buses and taxies have been developed to integrate land transportation services, such as trains, buses, and taxies. As well as autonomous vehicles and trains, autonomous ships require precise 3D maps and position data obtained by GNSS positioning. Therefore, we focus on 3D measurement with laser scanning and PPP-RTK with QZSS CLAS (centimeter-level augmentation service) to improve the accuracy and performance of GNSS positioning. However, rivers in urban areas, especially in Tokyo, have poor GNSS positioning environments such as places under bridges and highways. Thus, we also focus on Simultaneous Localization and Mapping (SLAM) using laser scanners as a self-positioning approach to achieve indoor-outdoor seamless positioning. In this study, we experimented with 3D river mapping for autonomous ships. We used two laser scanners and a multi-frequency GNSS receiver mounted on a quick charging plug-in electric boat. We selected two rivers as our study areas. The first is Kanda-gawa river as a typical river in Tokyo. The second is Nihonbashi-gawa river as a GNSS-denied environment. In this paper, we present the results of our preliminary experiments.

1. INTRODUCTION

In urban areas, especially in Tokyo, there are many rivers that can be used for water transportation systems using ships and boats. When the water transportation systems are linked to land transportation systems, advanced Mobility as a Service (MaaS) can be achieved. For transportation systems. In addition, many autonomous ships and boats should be used to automate infrastructure maintenance in daily operation. However, many sections of rivers in urban areas are poor GNSS positioning environments because of highways and buildings. Therefore, we focus on indoor-outdoor seamless Localization and Mapping (SLAM) using LiDAR and other devices (Durrant-Whyte and Bailey, 2006). Moreover, we focus on the use of low-price devices such as LiDAR and precise GNSS positioning for autonomous driving systems. We also focus on the use of PPP-RTK with QZSS (Quasi-Zenith Satellite Systems) to improve the performance of indoor-outdoor positioning. The QZSS uses the data of electronic reference points maintained in Japan for high-precision satellite positioning and calculates correction information using the electronic reference points (Motohisa, 2014). If the reference longitude and latitude coordinates are determined using older surveying techniques, highly accurate longitude and latitude coordinates may not always be obtained, but highly accurate positioning augmentation can be performed as earth-centered coordinates. The L6 signal used to transmit the centimeter-level position augmentation information is not a GPS signal, but a surveying technique called carrier positioning. However, by using surveying techniques, positioning can be done with an error of a few centimeters. However, by using surveying techniques, it is possible to achieve positioning with an error of only a few centimeters. Since there is a time lag of more than a dozen seconds between the creation of the augmentation information and its transmission via satellite, there is a possibility that sudden ionospheric disturbances may not be corrected in time and the positioning results may be disturbed. In this study, we experimented with 3D river mapping for autonomous ships. We used two laser scanners and a multi-frequency GNSS receiver mounted on a quick charging plug-in electric boat. We selected two rivers as our study areas. The first is Kanda-gawa river as a typical river in Tokyo, The second is Nihonbashi-gawa river as a GNSS-denied environment. In this paper, we present the result of our preliminary experiments.

2. METHOLOGY

Our methodology mainly consists of LiDAR and GNSS data acquisition, time synchronization and interpolation, initial orientation, and fine scan matching as shown in Figure 1. First, LiDAR and GNSS data are acquired from a boat. LiDAR is mounted on the front of the boat to acquire point clouds with horizontal and diagonal scanning. GNSS antenna for RTK and CLAS is mounted on the rooftop of the boat to acquire centimeter-level position data. GNSS position data is acquired once per second, and LiDAR data is acquired at 10 frames per second for distance data.

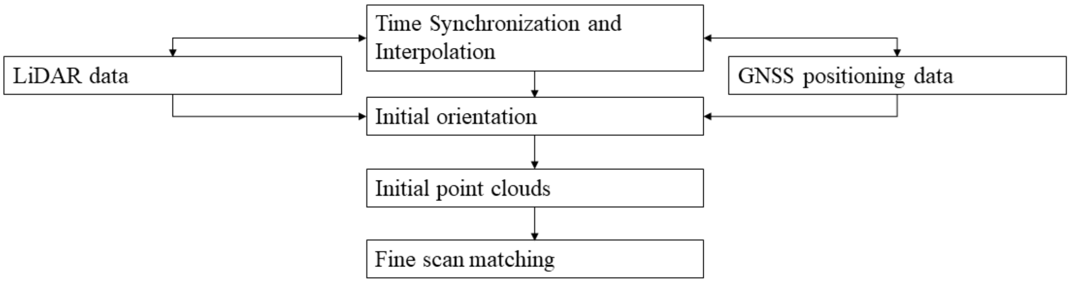


Figure 1. Proposed methodology

Second, in time synchronization and interpolation, LiDAR and GNSS position data are firstly synchronized using GNSS time. Next GNSS position data are interpolated to adjust to the sampling rate of LiDAR data.
Third, in initial orientation, point clouds are pre-registered using position and azimuth data. RTK-GNSS and CLAS position results are used as initial position data. Next, azimuth data are estimated using temporal differences of initial position data. Then LiDAR position and azimuth data are estimated using initial position and azimuth data with offset data from GNSS antenna to LiDAR.
Finally, fine scan matching is used to estimate the pose of the LiDAR; the distance data of the boat around the LiDAR is omitted because it significantly interferes with the estimation of the pose in a moving vehicle, increasing the processing time and degrading the accuracy. Since the obtained point cloud is sparse compared to the one obtained by the vehicle, NDT (Normal Distributions Transform) is used for estimation to extract the relative pose between the scan of the referenced frame and the current scan (Biber et al., 2003) (Hess et al., 2016).

3. Experiments Environments

We selected a part of Kanda-gawa River and Nihonbashi-gawa River from Asakusa-bashi Bridge to Eitai-bashi Bridge as our study areas. The measured route consists of two sections. The first section is Kanda-gawa River from Asakusa-bashi Bridge to Suido-bashi Bridge. Although many buildings exist along the river, the first section is assumed as GNSS visible environment. The second section is Nihonbashi-gawa River from Suido-bashi Bridge to Eitai-bashi Bridge under Tokyo metropolitan expressway. Although GNSS signals were received from several satellites, the second section is assumed as non-GNSS positioning environment. We used a quick charging plug-in electric boat (RAICHO-I) to reduce vibration in laser scanning and positioning. We acquired RTK-GNSS positioning data (ZED-F9D, u-blox), and PPP-RTK GNSS positioning data with CLAS (AsteRx4, CORE). We also acquired LiDAR data with VLP-16 (Velodyne). The LiDAR was mounted on the front of the boat due for clearance under bridges. In data acquisition, we used laptop PCs for each device and sensor. In point cloud processing, we used MATLAB with desktop PC (Intel Core-i9, 3.7GHz and 32GB RAM).

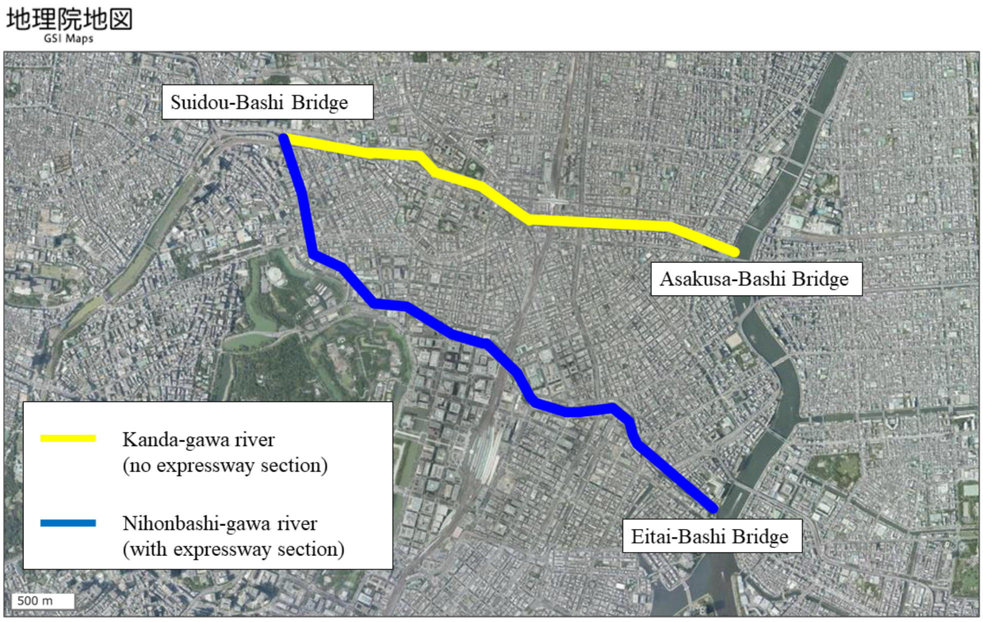


Figure 2. Measured route

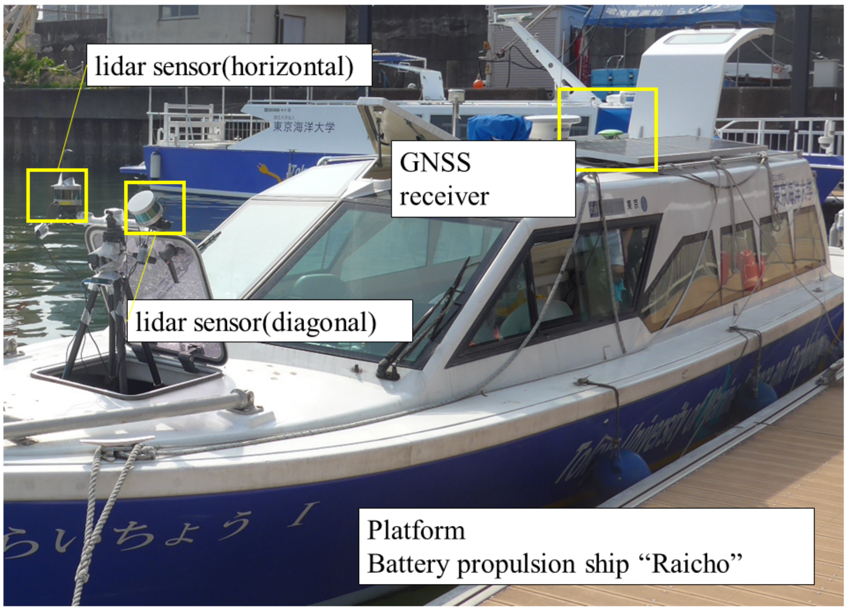


Figure 3 Measurement system

4. RESULTS

4.1 GNSS

GNSS positioning results are shown in Figure 4. In the first section, FIX solution in RTKGNSS and PPP-RTK positioning was obtained except for bridge sections. On the other hand, in the second section, FIX solutions in RTK-GNSS and PPP-RTK positioning were not obtained because of the non-GNSS positioning environment under the expressway. The difference of each positioning result was approximately within 5 to 10 cm in a horizontal direction.

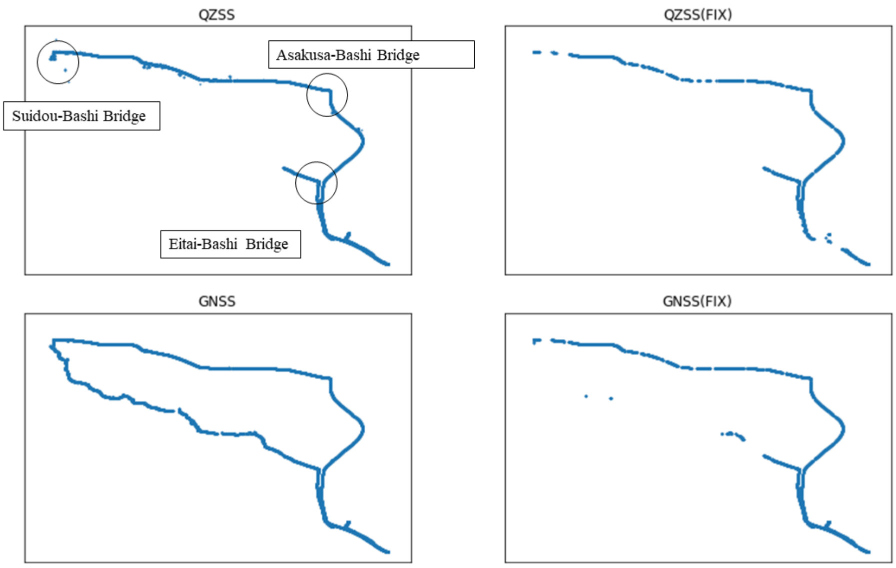


Figure 4 RTK-GNSS and QZSS positioning results

4.2 SLAM

The SLAM processing using point clouds acquired by horizontal scanning was processed successfully, as shown in Figure 5. In approximate overall areas, LiDAR position data were estimated even if anchored boats and expressways exist along with the measured areas, because complex features are assumed as excellent unique features for SLAM processing. However, the position estimation was failed at places along monotonous revetments and wide bridges, because fewer features exist for the SLAM processing. In addition, no information was obtained in a wide river because of outranges in the LiDAR measurement.

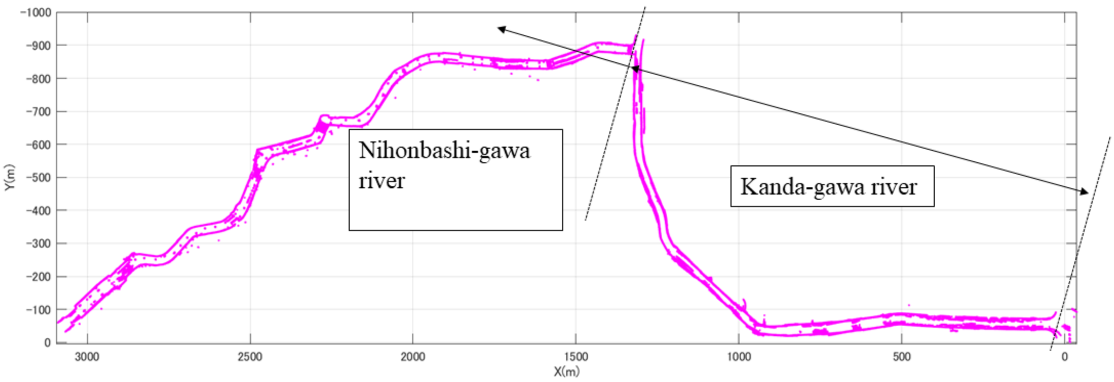


Figure 5. Result of SLAM processing (dataset 1)

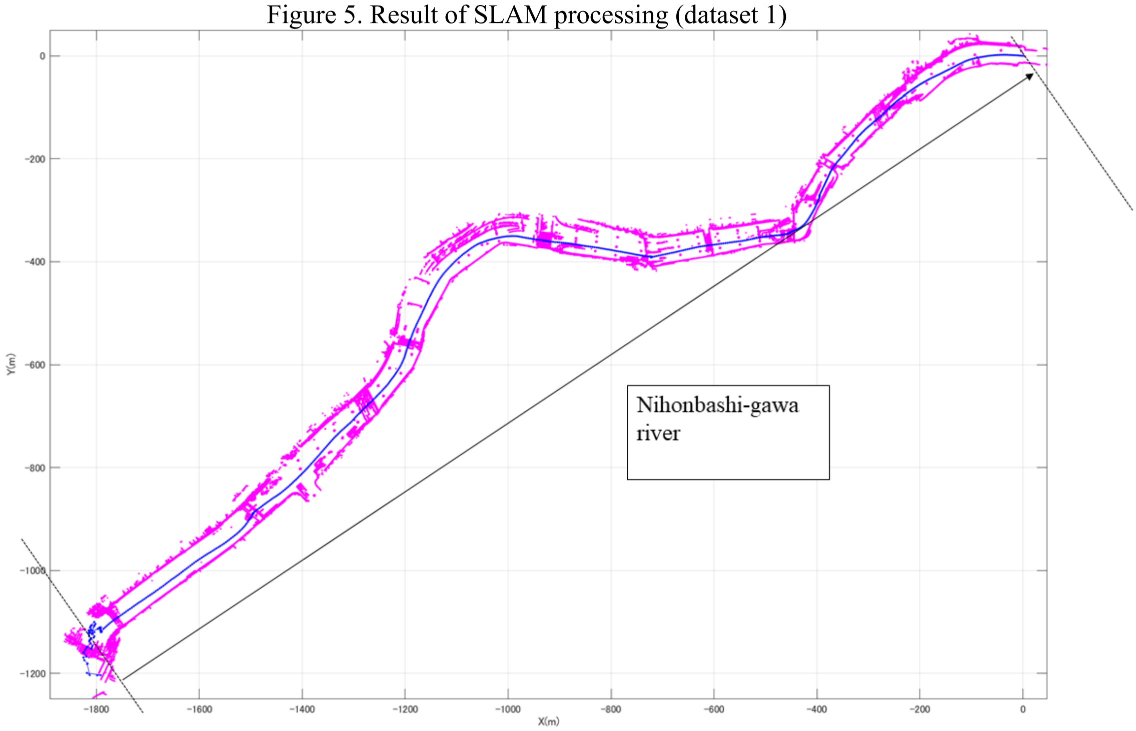


Figure 6. Result of SLAM processing (dataset 2)

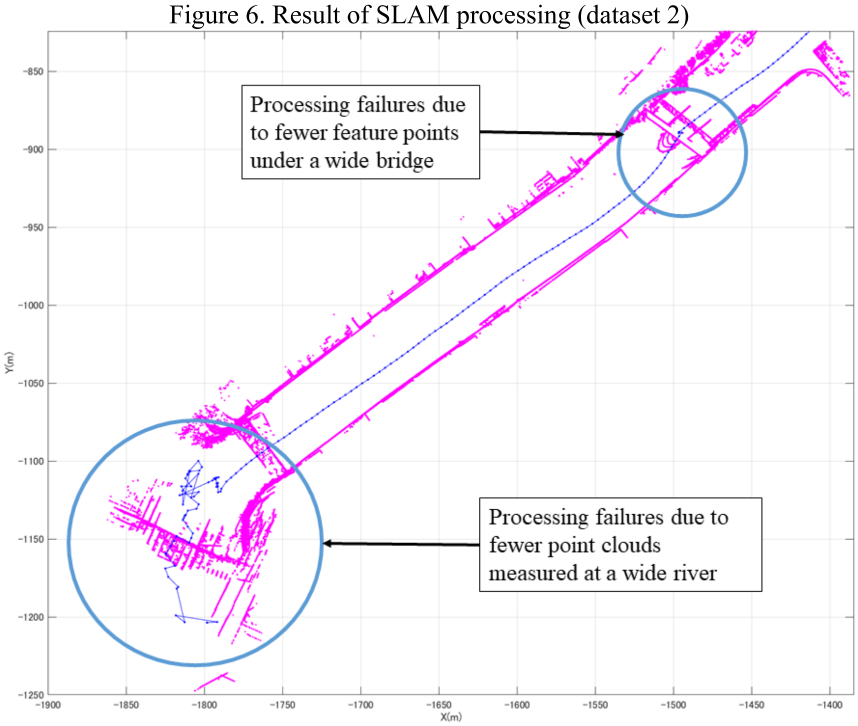
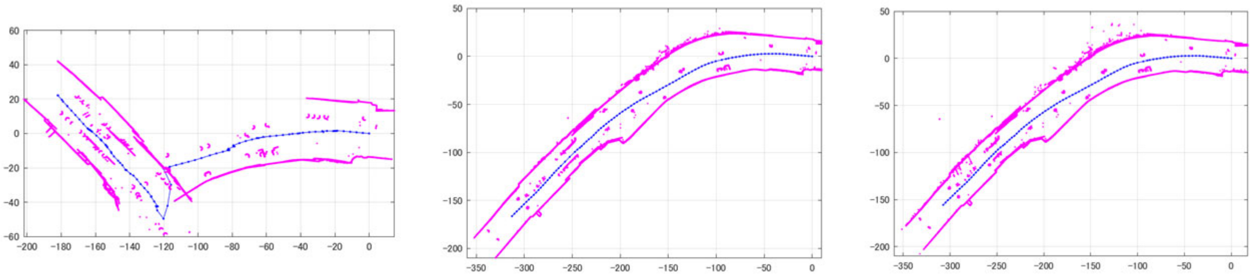


Figure 7. Failed example in SLAM processing

5. Discussion

We set thresholds of distance values used at 20[m] (pattern A), 50[m] (pattern B), and 70[m] (pattern C) to find better parameters for SLAM to improve the processing speed and accuracy. We confirmed that the pattern A was not enough to detect features for SLAM processing at places surrounded by monotonous objects. We also confirmed that the pattern B and C can estimate precise result stably. However, in the processing time, the pattern C was extended by about approximately 2.75 times to the pattern. Therefore, we selected the threshold value of 50[m] as better threshold values for the SLAM processing in river mapping at our study areas.



Maximam distancefor SLAM processing : 20[m] Processing Time : 89[s]	Maximam distancefor SLAM processing : 50[m] Processing Time : 488[s]	Maximam distancefor SLAM processing : 70[m] Processing Time : 1343[s]

Figure 8. Results of SLAM with each threshold (maximum distance)

5.1 The first section (without expressway)

We confirmed that SLAM with GNSS was effective in the section without the expressway. When the ratio of Fixed in RTK-GNSS positioning is approximately 100%. GNSS positioning results can be used for sensor positions directly to avoid failures of SLAM processing in the monotonous feature areas including continuous revetments or wide rivers. Although SLAM processing and GNSS positioning were unstable under wide bridges, we confirmed that interpolated GNSS positioning results can be used when the boat runs along a straight path. We also confirmed that the multi-layer LiDAR is useful to improve SLAM processing because multi-scan lines with ±15 degrees can generate cross-section data from point clouds of revetments and buildings.

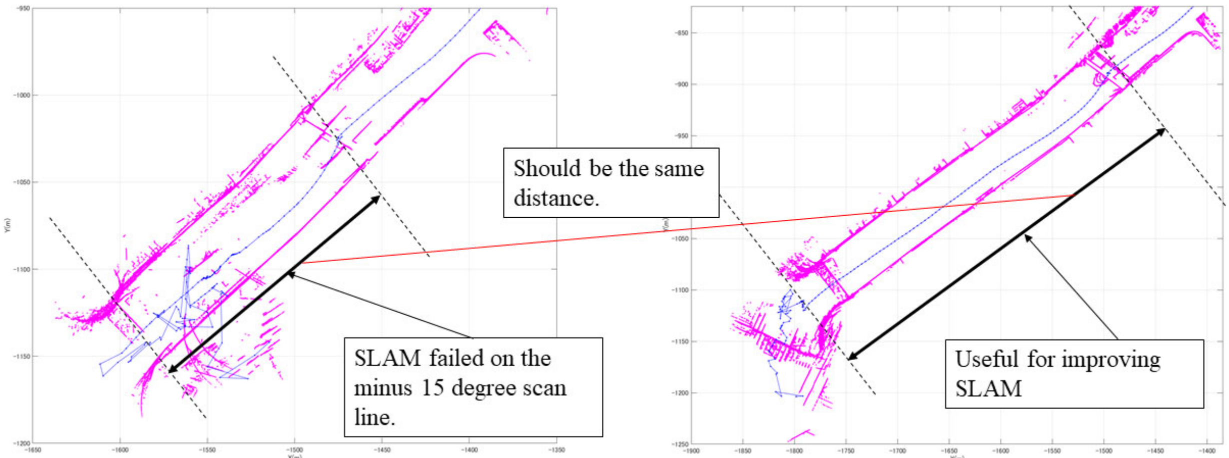


Figure 9. SLAM processing results (left: failed result, right: succeeded result)

5.2 The second section (under expressway)

Although GNSS positioning results could not be obtained in the second section under the expressway, SLAM processing was stable because the measured revetments and piers of the expressway were excellent features for SLAM processing. However, SLAM processing was unstable under wide bridges. In addition, the accumulated error adjustment in SLAM processing was not available because the measurement loop was not prepared due to outrange of LiDAR measurement at the wide river from Asakusa-bashi to Eitai-bashi. As our future works, we will develop a methodology of 3D mapping with point clouds and images captured with omni-directional cameras.

6. CONCLUSION

We examined how to combine GNSS positioning and SLAM for 3D river mapping for autonomous ships. Through experiments of laser scanning from quick charging plug-in electric boat, we confirmed that a combination of laser scanning and GNSS positioning can be used for river mapping in urban areas. We clarified that the stable and unstable areas for SLAM and GNSS positioning for autonomous navigation systems. We also evaluated a threshold value of distance in SLAM processing for river mapping urban areas.

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