LIDAR-BASED MULTI-SENSOR MODULE DEVELOPMENT AND ASSESSMENT OF APPLICABILITY FOR DAMAGE INVESTIGATION OF INDOOR DISASTER

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ABSTRACT:

As the risk of disaster scenes increases, the number of cases of acquiring disaster scenes information using unmanned robots is increasing. Because unmanned robots can be remotely controlled, sensors such as LiDAR and optical cameras are installed so that investigators can safely observe disaster scenes and acquire information. In particular, the information that can be acquired is different depending on the sensor characteristics, and a sensor module suitable for the purpose is being developed. Accordingly, the National Disaster Management research Institute(NDMI) also developed a investigation robot capable of acquiring information on disaster sites independently. Based on 3D point cloud data, we developed a multi-sensor module and SLAM algorithm customized to the investigation robot to collect quantitative information on the damage situation. To test the performance of the independently developed multi-sensor module, SLAM mapping was performed in a disaster building reproduced like a disaster scene, and various SLAM algorithms and distance comparison were performed. As a result, PackSLAM developed in this study showed the lowest error. In the future, to increase applicability at disaster sites, more precise experiments will be conducted by conducted by establishing a rough terrain environment.

1. INTRODUCTION

It is difficult to receive GNSS information from the outside in an indoor space. Therefore, the indoor space is mapped using the SLAM technique that can measure the location of the mobile platform while generating a high precision map of the surrounding environment using the multiple observation sensors mounted on the mobile platform (Thrun et al., 2005; Kaess et al., 2012; Zlot et al., 2012).

In addition, it is hard for investigators to directly perform damage investigations at indoor disaster sites of collapsed accidents due to the complex structure and dangerous environment. For this reason, unmanned robots equipped with advanced observation sensors such as optical, infrared cameras, or LiDAR are being used to acquire recent disaster damage information about indoor spaces and identify those who need to rescue.

Since the unmanned robot can be controlled remotely in an area that is difficult for investigators to access, it is possible to easily obtain the safety of the investigator and necessary information.

According to a recent previous study, in order to develop a continuum robot system with various information collection functions, a study was conducted to install several small sensors in a distributed manner(Yamauchi et al., 2022). Also, various robots are being developed according to the purpose of fire response and fire suppression, underwater inspection of bridges, and damage recovery(Park et al., 2017; Paravisi et al., 2019; Gan et al., 2021)..

As unmanned robots for disaster safety, Shark Robotics Colossus of France, iRobot of FLIR of USA, Spot of Boston Dynamics of USA, etc. are being developed, and the NDMI has Packbot of iRobot acquired in 2017.

Therefore, this study suggests a multi-sensor module that can be mounted on an investigation robot (iRobot Packbot) to acquire damage information when performing an indoor disaster site damage investigation considering the characteristics of SLAM. Also, LiDAR-based SLAM algorithm customized for the multi-sensor module of the investigation robot for indoor spatial mapping is suggested and its applicability for indoor damage investigation is evaluated in this paper.

2. METHOD

2.1 Development of Multiple Sensor Module

The multi-sensor module is composed of LiDAR-IMU-NUC. LiDAR is Ouster OS1-32, IMU is VectorNav VN100, and NUC is a model equipped with an Intel i5 CPU. The most important part of a system that utilizes data acquired from a sensor module composed of multiple sensors is that the sensor data should be synchronized with one system clock.

In particular, in the SLAM algorithm, which uses LiDAR (perceptive sensor) and IMU (proprioceptive sensor) as a strongly coupled system, it is important to synchronize as the same time zone the data measured in real-time and the data is transmitted.

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The multi-sensor module is a Linux-based operating system using an Intel NUC 8th generation development board equipped with an Intel Core i5 CPU, and is a synchronized system that can receive sensor data in real time through real-time kernel patching.
Therefore, To utilize the synchronized time in the SLAM system that performs indoor positioning and mapping, this study used a timestamp method that displays the reception time of the data received through the sensor communication protocol as the time of the computing unit.
Synchronized sensor data can be used through an interface using the ROS (Robot Operating System) platform, and it is possible to check the reception frequency whether the sensor data acquired from Ouster OS1-32 LiDAR and VectorNav VN100 IMU are being received in real time(Figure 1 ~ 2).

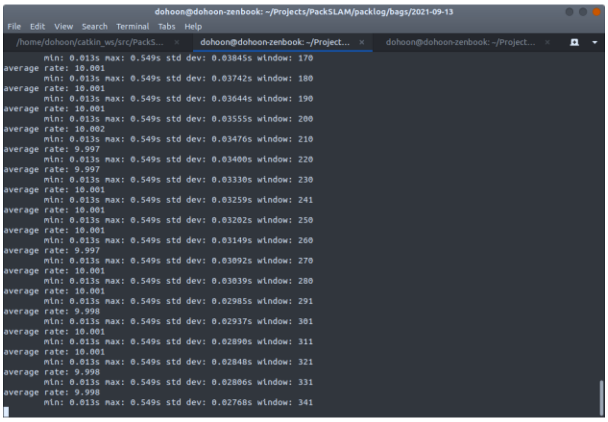

Figure 1. Ouster OS1-32 LiDR data ROS reception speed

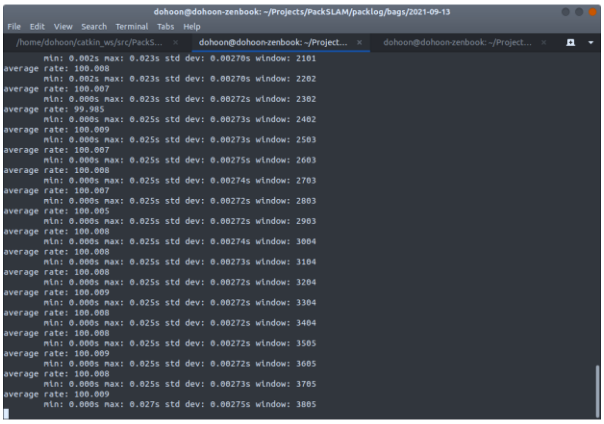

Figure 2. VectorNav VN100 IMU data ROS reception speed

When power is supplied from an external battery, power is distributed to each sensor, and then data acquisition starts from the internal board of each LiDAR and IMU, it can be checked through the ROS (Robot Operating System) platform. Finally, the multi-sensor module was combined with an external battery, a wireless network router, and a module mount, and was boarded next to the investigation robot's arm (Figure 3 and table 1).

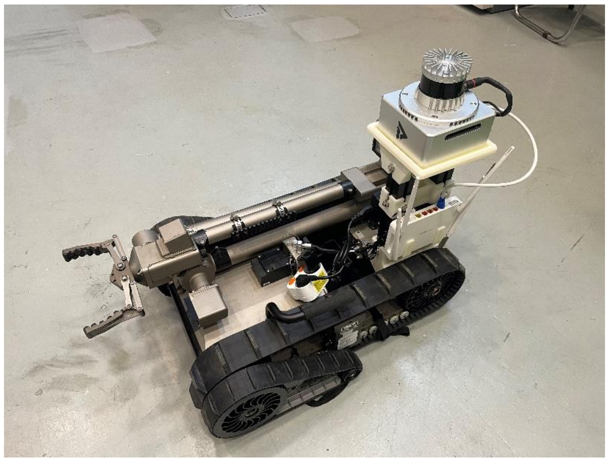

Figure 3. Investigation robot multi-sensor module

Module	Component	feature
Multi-sensor	LiDAR	Ouster OS1-32
	IMU	VctorNav VN100
	NUC	Intel NUC8v-5PNB
Mount	Mount	3D printing
Power supply	Battery	4S, Li0ion 40800mAh
	DC adapter	19V, 120W
Communication device	Wireless network router	ipTime A604

Table 1. Composition of final multi-sensor module

2.2 SLAM based Indoor Mapping

LOAM is a representative LiDAR-based SLAM algorithm widely used for real-time indoor mapping. To obtain real-time performance, LOAM estimates the posture of 6-DOF (Degree of Freedom) using point cloud data through a software system parallel configuration and simultaneously performs voxel-based mapping (Zhang et al., 2014).
The LIO-SAM (LiDAR Inertial Odometry via Smoothing and Mapping) algorithm, derived from LOAM, includes an IMU constructed using a coefficient graph of a rigidly coupled system of LiDAR and an inertial measurement device. And it has a positioning module, a mapping module that optimizes the point cloud map, and real-time performance, so it is composed of an optimization system suitable for a multi-sensor system(Shan et al., 2020, Figure 4).
In addition, it is a SLAM system that can calculate reliable results by using other sensors even in areas where the positioning reliability of LiDAR and IMU is low by configuring an integrated system between various sensors such as GNSS that provides real coordinates.

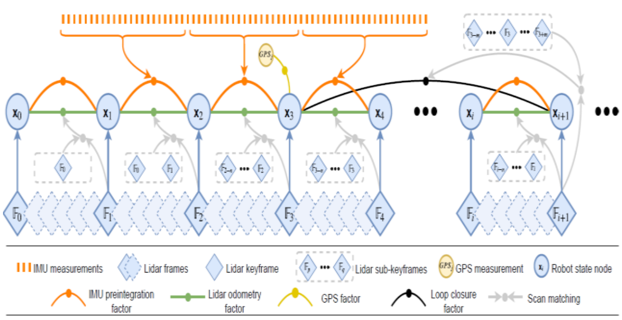

Figure 4. System structure of LIO-SAM factor graph

Based on the LIO-SAM algorithm, this study calculates the ring field(correspondence) and time field (motion distortion) of the 3D point cloud data, which were not available in the multi-sensor module, and expresses the points as a 5D vector with a total of 5 values including 3D spatial information(Figure 5). The ring field removes false associations between point clouds when searching for correspondence for ICP registration, and the time field is used to correct motion distortion included in the point cloud data.
The additionally calculated information was implemented to be utilized in the multi-sensor module, and a customized SLAM algorithm for the multiple sensor module of the investigation robot called PackSLAM was developed.

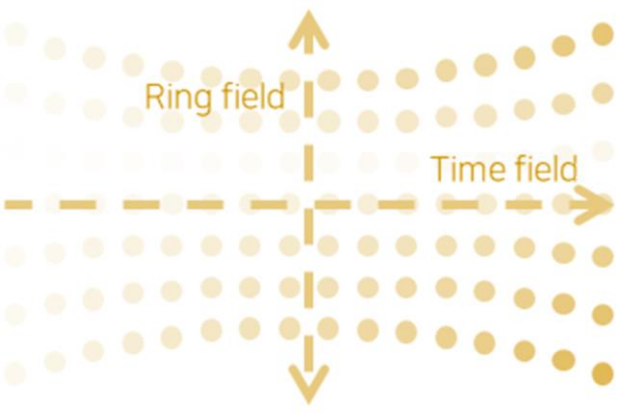

Figure 5. Concept of ring/time field

2.3 Study Area

In this study, multi-sensor module customized SLAM algorithm experiment was performed in the disaster environment building of the Disaster Robotics Centre of the Korea Institute of Robotics & Technology Convergence(KIRO) located in Buk-gu, Pohang-si, Republic of Korea.
The disaster environment building consists of several rooms and two floors, and is designed similarly to the disaster environment because various auxiliary materials are distributed.
For this reason, empirical experiments and research on various robots related to disaster safety are being conducted.
Figure 6 shows the front view of the disaster building, and Figure 7 shows the interior of the disaster building.
In this study, quantitative numerical analysis of indoor space was performed by acquiring 3D point cloud data through PackSLAM on the second floor of a disaster building.

Figure 6. Disaster environment building of disaster robotics centre

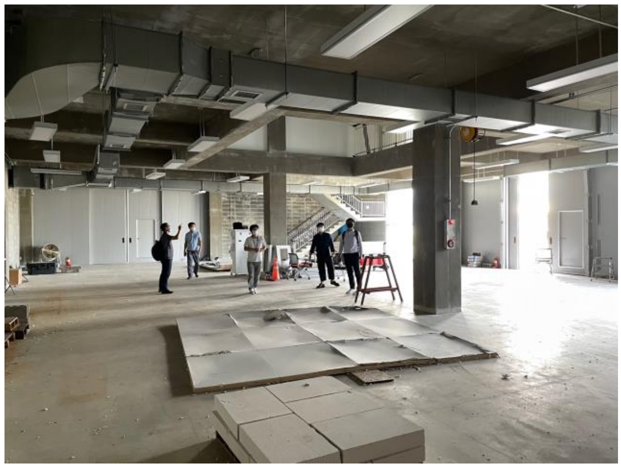

Figure 7. Interior view of disaster building

3. RESULTS AND DISCUSSIONS

To evaluate the accuracy of the 3D point cloud data acquired with PackSLAM, LiDAR data acquired from Leica BLK360 was used as reference data (ground truth).
BLK360 is a compact LiDAR that is specialized for portability, so it is widely used for indoor space mapping.
Although it is manufactured in a small size, it has good performance such as wavelength 830 nm, range accuracy 4 mm @ 10 m, and point density 5 mm @ 10 m (Figure. 8 and Table 2).

Figure 8. Leica BLK360

Division	Specification
Class	Laser class 1
Wavelength	830 nm
Coverage accuracy	4 mm @ 10 m, 7 mm @ 20 m
FOV	300° (V) × 360°(H)
Precision	- 20 mm @ 10 m(fast) - 10 mm @ 10 m(normal) - 5 mm @ 10 m(high density)

Table 2. BLK360 specifications

And to compare the accuracy of the PackSLAM developed in this study, data were also acquired with the A-LOAM, LeGO-LOAM, and LIO-SAM algorithms among the LOAM-type algorithms(Toschi et al., 2015).
Figure 9 to 11 show the 3D point clouds acquired by the LOAM series algorithm, and Figure 12 shows the 3D point clouds acquired by PackSLAM.

Figure 9. A-LOAM result

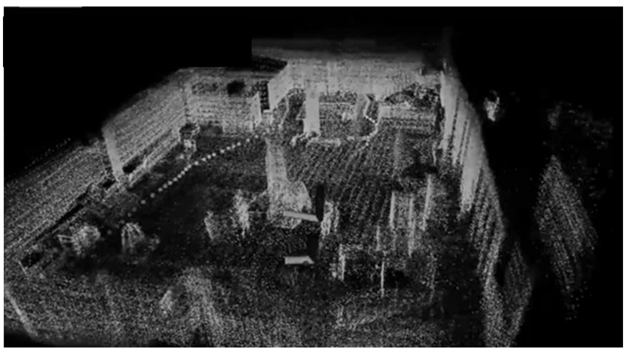

Figure 10. LeGO-LOAM

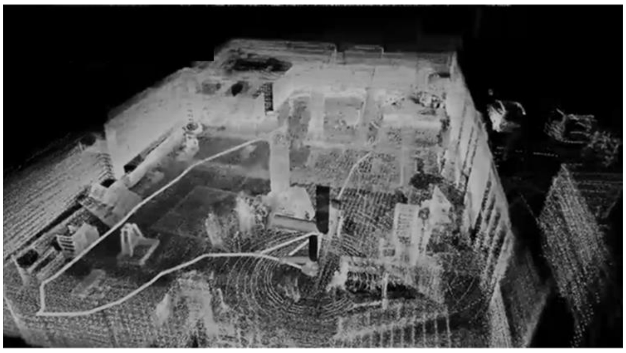

Figure 11. LIO-SAM

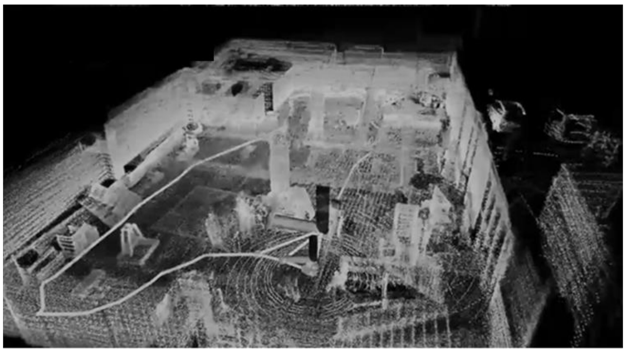

Figure 12. PackSLAM result

Accuracy evaluation was performed by dividing three sections within the second floor of the disaster building and calculating the distance for each section(Figure 13). And quantitative accuracy comparison was performed through BLK360.
This method divides some areas from 3D point cloud data to measure the distance between areas, selects an area with a uniform shape such as a wall, and calculates the distance observation error through the nearest method to evaluate the accuracy.
As a result, obtained by calculating the distance between point clouds, the average value and distribution of distance values can be obtained.
The average distance can be used as a measure to evaluate the accuracy of the geometric structure of the generated entire spatial map.
Figure 14 explains the concept of the accuracy evaluation technique as a figure.

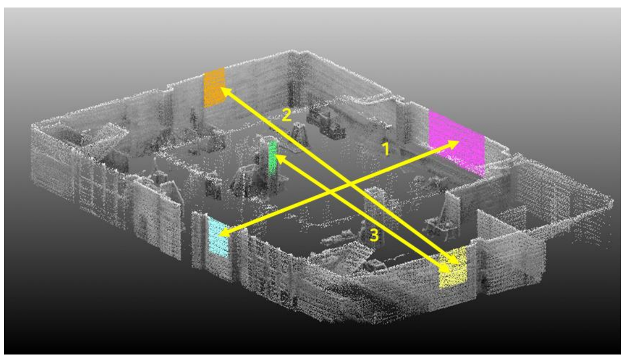

Figure 13. Distance measurement section for accuracy assessment

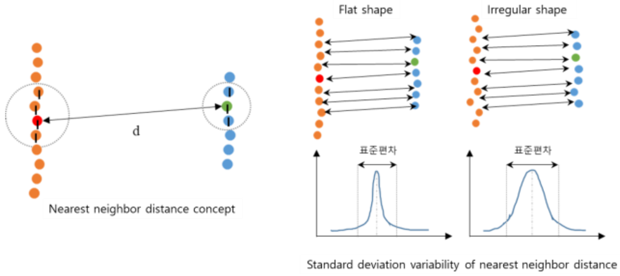

Figure 14. Schematic diagram of accuracy evaluation method

As a result of the above evaluation, PackSLAM showed the lowest error than other SLAM algorithms in all sections, as shown in table 3~5.

A-LOAM and LeGO-LOAM used only LiDAR information, whereas LIO-SAM and PackSLAM algorithms showed better excellent performance because they optimized the graph using the combined system of LiDAR and IMU(Shan et al., 2020).

SLAM type	Avg. distance(m)	St. dev.(m)	Error(m)
A-LOAM	16.351	0.203	-0.115
LeGO-LOAM	16.376	0.195	-0.140
LIO-SAM	16.298	0.043	-0.062
PackSLAM	16.225	0.066	0.011
BLK360	16.236	0.047	-

Table 3. Accuracy assessment at Sect. 1

SLAM type	Avg. distance(m)	St. dev.(m)	Error(m)
A-LOAM	24.589	0.103	0.214
LeGO-LOAM	24.630	0.094	0.173
LIO-SAM	24.821	0.083	-0.018
PackSLAM	24.810	0.083	-0.007
BLK360	24.803	0.053	-

Table 4. Accuracy assessment at Sect. 2

SLAM type	Avg. distance(m)	St. dev.(m)	Error(m)
A-LOAM	15.895	0.076	-0.037
LeGO-LOAM	15.724	0.032	0.134
LIO-SAM	15.874	0.050	-0.016
PackSLAM	15.873	0.051	-0.015
BLK360	15.858	0.009	-

Table 5. Accuracy assessment at Sect. 3

Looking at the distance accuracy by section, the algorithm that showed the most similar results to BLK360 in section 1 is PackSLAM. PackSLAM showed the lowest error of 0.011 m, whereas LeGO-LOAM showed the highest error of 0.140 m.

Similarly for section 2, PackSLAM showed the lowest error of 0.007 m. The algorithm showing the highest error is A-LOAM. It was 0.214 m, which showed a large error of over 20 cm.

Finally, in section 3, PackSLAM also showed the lowest error at 0.015 m. The algorithm with the highest error is LeGO-LOAM.

As a result of the distance error analysis for each section, the error was generally high in the order of PackSLAM → LIO-SAM → A-LOAM → LeGO-LOAM.

In the case of PackSLAM, it was found that the method using the point cloud correlation of the ring field and the distortion correction of the time field can obtain improved results compared to the existing LIO-SAM.

4. CONCLUSION

In this study, the multi-sensor module that can be mounted on an investigation robot was developed. Also, a suggested PackSLAM algorithm customized for the investigation robot, was developed. In conclusion, the PackSLAM suggested in this paper showed observation performance with an error of less than 2 cm and demonstrated the applicability for investigating indoor disaster sites.

In the future, it is expected to quickly and accurately acquire disaster damage information by being deployed to indoor disaster sites that are difficult for investigators to access due to earthquakes or collapse accidents.

However, since this study only performed distance analysis for indoor space, it is necessary to expand field applicability by performing more various experiments based on the accuracy shown in the study results.

In order to be put into actual disaster scenes and used as immediate response equipment, we plan to conduct research by increasing the difficulty of the experiment by constructing a rough terrain rather than a flat area.

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