DEVELOPMENT OF MULTI-SENSOR MODULE MOUNTED MOBILE ROBOT FOR DISASTER FIELD INVESTIGATION

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Commission Ⅲ, ICWG Ⅲ/Ⅳa

KEY WORDS: Disaster, Man-made incident, Robot, Multi-sensor Module, LiDAR, Damage Investigation.

ABSTRACT:

Disasters are not easy to predict because they occur suddenly, and the scale of disasters is increasing compared to the past. Since a new type of disaster field always appears, when a disaster occurs, responders who are put into the site recognize the same risk as secondary damage and are put into the field. In this regard, the robot performs missions such as search and rescue in the initial response process at the disaster field. It is a technology with high potential to reduce damage to people and property. Most of the robots are equipped with site accessibility and monitoring through cameras and remote control, but considering the specificity of the disaster field, it is not easy to fully monitor the site with a camera sensor as the possibility of poor visibility is very high. LiDAR uses a laser to recognize the distance to a nearby object in a relatively wide range and acquires three-dimensional information, so its accuracy and precision are higher than other sensors.

In this study, one multi-sensor module was manufactured by combining LiDAR and IMU sensor with a computing board for real-time monitoring so that it could be used in the field of robots. In addition, we studied how to stably mount this multi-sensor module to a robot so that it can maintain optimal accuracy at disaster field, and it is intended to be utilized as a prior research for field operation of robots equipped with sensors in the future.

1. RESEARCH BACKGROUND AND PURPOSE

In Korea, disasters are those that can cause damage to people's lives, bodies, property, and the nation, and are defined as natural disasters and social disasters. Common recurrent disasters include typhoons, floods, heavy rains, and strong winds, while social disasters include fire, collapse, explosion, and traffic accidents. In addition, there is damage due to the spread of infectious diseases, livestock infectious diseases, and fine dust. Although the Korean government is promoting and striving for systematic disaster management as an efficient operation, these disasters are not easy to predict because they occur suddenly, and the damage is increasing because the scale is larger than in the past (Lee et al., 2021). And, disasters that have occurred often develop into secondary disasters for various reasons. For example, if a natural disaster such as heavy rain or snowfall occurs, it can cause rivers to overflow or cause landslides. If these disasters affect the cities and villages where citizens live, they can spread as secondary damage. Therefore, when a single disaster occurs, several competent ministries cooperate with each other to manage it.

Disaster management is divided into four stages: prevention, preparation, response, and recovery. After an emergency or disaster, which is one of the four stages, the corresponding response stage includes search and rescue, operation of shelters, and medical support. In particular, a lot of attention and concentration are focused on search and rescue. Since a new type of disaster field always appears, when a disaster occurs, responders who are put into the site recognize the same risk as secondary damage and are put into the field. In general, firefighters who respond the most are often injured or killed during the on-site response process. In this regard, the robot performs missions such as search and rescue in the initial response process at the disaster field. It is a technology with high potential to reduce damage to life and property (Oh and Kim, 2020).

Robots have been continuously researched in many countries for a long time. In particular, interest in disaster response robots for the purpose of preventing spread, reducing damage, and promptly responding to disasters at disaster fields is very high. Shark Robotics' Colossus, which was put into operation at the site of the Notre Dame Cathedral fire in 2019, can spray water up to 250 meters and remote control it from about 304 meters away. iRobot Packbot is capable of performing tasks such as dismantling explosives, monitoring, and reconnaissance. A robot that walks on four legs Boston Dynamics' Spot can overcome obstacles such as rough roads and stairs, and Mellon University in the US has developed a snake-shaped robot. It has already been proven that robots can replace humans in response to disaster fields (Kang et al., 2016; Lee et al., 2007).

Most of the robots are equipped with site accessibility and monitoring through cameras and remote control, but considering the specificity of the disaster fields, it is not easy to fully monitor the site with a camera sensor as the possibility of poor visibility is very high. The sensor LiDAR that can overcome these limitations is the optimal sensor. LiDAR uses a

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https://doi.org/10.5194/isprs-archives-XLIII-B3-2022-1103-2022 |

laser to recognize the distance to nearby objects in a relatively wide range and acquire 3D information, so it has higher accuracy and precision than other sensors, it is attracting attention as a key sensor in the industry. (Choi, 2011; Kim et al., 2012). In addition, SLAM (Simultaneous Localization and Mapping) technology has the advantage of mapping disaster fields in real time using only LiDAR sensors to obtain more accurate site information. And, in order to utilize SLAM at the disaster fields, the stability of the mounted sensor should be improved, and then the mounting should be done so that it can be less affected by vibrations that occur during movement, and the more accurate the data can be obtained. No matter how good the sensor is, if the environment is not suitable, there will be a lot of errors in the information about the field, and the reliability will inevitably be lowered.

Therefore, in this study, one multi-sensor module was manufactured by combining LiDAR and IMU sensor with a computing board for real-time monitoring so that it could be used in the field of robots. In addition, we studied how to stably mount this multi-sensor module to a robot so that it can maintain optimal accuracy at disaster fields, and it is intended to be utilized as a prior research for field operation of robots equipped with sensors in the future.

2. RESEARCH PLATFORMS AND METHOD

2.1 Used Mobile Robot

The disaster robot used in this study is the iRobot Packbot 501 model (Fig. 1).

Figure 1. iRobot Packbot 501

Packbot is a robot modified by Morticia for military use by the US iRobot company with the support of the Ministry of National Defense. It was used for ground operations during the Iraq War. After improving its performance, it was proved that it can be used in an actual disaster environment, as it was usefully used to investigate the inside of a nuclear reactor that cannot be entered in the Fukushima nuclear accident in 2011 (Cho and Jeong, 2011).

Packbot is a caterpillar tread type, and the body is 70cm long, 53cm wide, and weighs 35kg. Packbot allows the operator to easily respond to forward/backward and left/right direction change through 4 cameras through the remote controller, and is designed to be robustly designed not to be affected by environmental factors such as shock or weather. In addition, as it has a tong arm, it is possible to lift (4.5~15kg) and tow (50kg), and it is also possible to collect samples, so it is suitable for use at disaster fields. Nuclear accidents such as the Fukushima nuclear accident do not occur frequently. In addition, as shown above, the form of Packbot can sufficiently perform missions on behalf of people even in indoor sites such as building collapse.

In this study, it is intended to be used for search and on-site monitoring at more diverse disaster fields by loading sensors such as LiDAR that Packbot has.

2.2 Development of Multi-sensor Modules

The most important sensor to be mounted on the robot in this study is LiDAR. It should be possible to scan the site in an intact state even with a LiDAR on it. The LiDAR to be mounted on the robot in this study is Ouster OS1-32. Ouster OS1 is a 32-channel mechanical LiDAR with a horizontal resolution of 512/1024/2048 points, a vertical angle of view of 45° (±22.5°), a maximum measuring distance of 120m, and an accuracy of ±0.7cm. The size and weight were considered to be mounted on the survey robot and operated. In order to maintain and improve LiDAR scan accuracy, an IMU (VectorNav VN100) sensor and LiDAR data are stored and output, and a computing board is installed for real-time monitoring. For ease of mounting, LiDAR, IMU, and computing board were manufactured as one multi-sensor module. (Fig. 2).

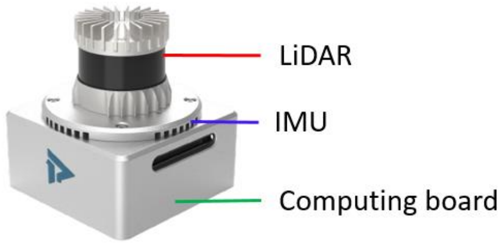

Figure 2. Configuration of multi-sensor module

In order for the manufactured multi-sensor module to be mounted on the robot and to maintain high accuracy, it is important to find the optimal position in consideration of the robot's appearance and operation method. In addition, it is important to consider the scanning range of the LiDAR sensor and to find a height that can minimize the effect of vibration that occurs when the robot is operated. Therefore, the position of the mount is determined in consideration of the appearance and operation characteristics of Packbot, the research robot used in this study. By experimenting while changing the mounting height of the multi-sensor module, we want to select a height at which the LiDAR can perform optimal scanning.

3. RESULTS ANALYSIS

3.1 Mounted Position Determination of Multi-sensor Module

The mounting position of the multi-sensor module is shown in Fig 3. As shown in 3, the mounting point for the original radiation sensor of the robot arm and the body mounting point located on the motor side of the body were most likely. When the sensor is mounted on the robot arm, the orientation and position of the module can be freely adjusted, but it was found that the shaking of the part corresponding to the joint of the arm occurs during operation of the robot. Therefore, it was judged that the mounting point of the vehicle body that can fix the sensor module with less shaking was appropriate.

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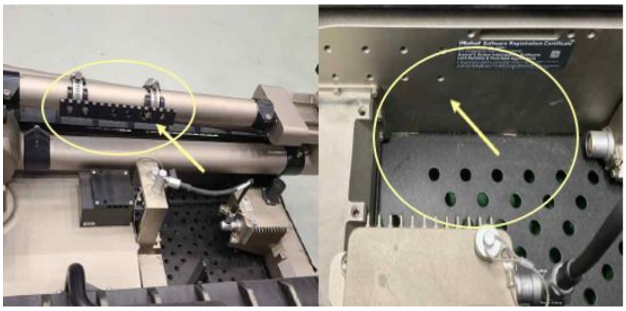
Figure 3. Mount location (Left: Arm, Right: Body)

In addition, an integrated mount capable of combining the body and multiple sensor modules was designed and manufactured for the ease of scanning the sensor module while fixing it to the floor and side surfaces (Fig. 4).


Figure 4. Integrated mount

The integrated mount was designed as a 3D CAD model, and it was manufactured by 3D printing and composed of parts such as an aluminum profile and fastening bolts/nuts.

3.2 Vibration Reduction Device

The multi-sensor module and Packbot were combined using the manufactured integrated mount. At this time, vibration reduction device was required to reduce vibration while accurately combining. To do so, it is necessary to first grasp in detail the magnitude and shape of the vibration transmitted to the module through Packbot.
Packbot used in the study selects three operating modes using a controller to adjust the speed. Therefore, the frequency of vibration is not constant, and the acceleration transmitted to the module was up to about 25 m/s^2. This is because the shape of the vibration is atypical, and the rotation speed of the two caterpillar threads generated in rotation and linear motion is different. Usually, a vibration reduction device consists of an elastic body for reducing the amplitude of vibration and an attenuation device that converts vibration energy to reduce it (Fig. 5).


Figure 5. Vibration reduction device processing

Therefore, the form of the dustproof system used for the Packbot is a dustproof pad made of polyurethane. It puts the dustproof pad between the module and the integrated mount, the integrated mount and the Packbot. Through this, it was designed to reduce vibrations in the vertical and horizontal directions.

3.3 Field Operation Scenario

Packbot is a caterpillar tread, and rubber wheels with strong resistance are advantageous for driving in rough terrain such as disaster fields, and have strengths in overcoming various obstacles with frictional force acting on the ground. However, there is a disadvantage in that a lot of vibration occurs due to these characteristics. In addition, as the speed increases, the vibration period becomes shorter and the vibration level increases, so it is necessary to understand the vibration caused by the basic Packbot driving.
Packbot basically has 3 speed modes: Creep, Normal, and Fast. The operation mode was divided into linear motion and rotational motion, and driving was performed in each mode, and the level of vibration generated during operation was identified through the acceleration measured by the accelerometer among the collected IMU data. In creep mode, vibrations of less than 5m/s^2 were generally detected, and vibrations of up to 15m/s^2 were detected in normal mode and fast mode. And it was confirmed that the level of vibration was higher in linear motion than in rotational motion. In the operation test, the vibration was not enough to damage the multi-module sensor, but it was judged that it was necessary to reduce the vibration when it was assumed that it was actually used at the disaster field. Assuming that the robot is equipped with a multi-sensor module, the operating scenario for indoor mapping of the current Packbot is summarized by considering various factors as well as the vibration level. For the scenario, the operating scale is 2000m3, the mode is Creep or Normal, and the Packbot arm is deactivated (fixed).

3.4 Height Determination of Multi-sensor Module

As the height of the multi-sensor module increases, the amplitude of vibration transmitted from the vehicle body increases, making it difficult to obtain scan data with desired accuracy. However, if the height is too low, the scanning range of the LiDAR is covered by surrounding obstacles, and desired scan data cannot be acquired. Therefore, it is important to select the height of the multi-sensor module to be mounted on the research robot.
In this study, in order to give the diversity of the height of the integrated mount that combines the multi-sensor module and the Packbot, the experiment was divided into three cases: 15Cm, 30Cm, and 50Cm. Packbot was divided into Creep and Normal, and the acceleration measured according to each height was compared. In the vibration level experiment, the distance was about 10 m, and linear and rotational motions were performed. Vibration level comparison was confirmed through the acceleration measured by the accelerometer among the IMU data.

This contribution has been peer-reviewed.
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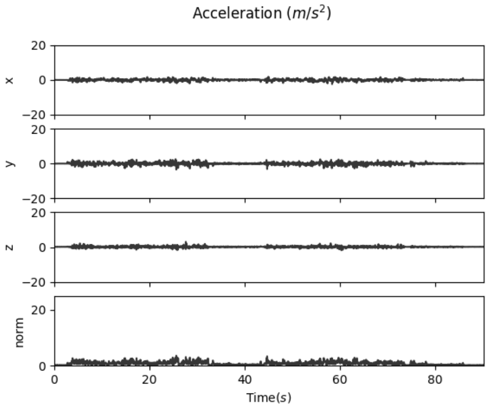

Figure 6. Vibration level of module (Creep, 15cm)

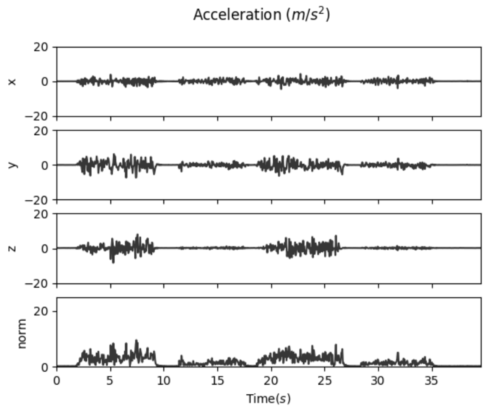

Figure 7. Vibration level of module (Normal, 15cm)

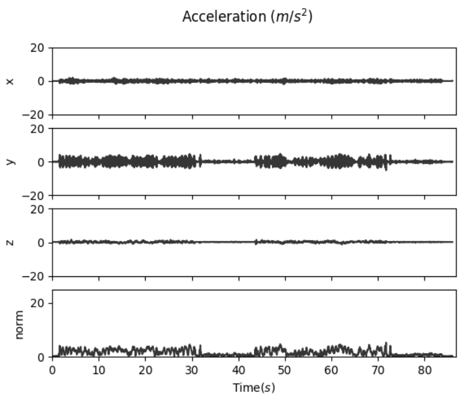

Figure 8. Vibration level of module (Creep, 30cm)

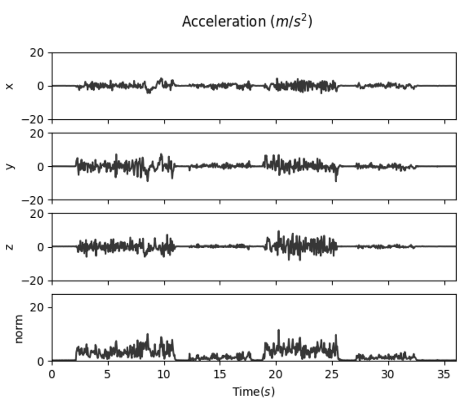

Figure 9. Vibration level of module (Normal, 30cm)

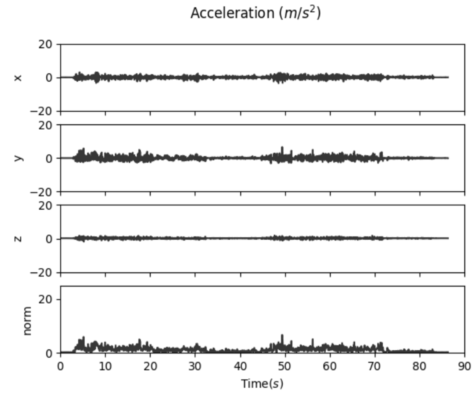

Figure 10. Vibration level of module (Creep, 50cm)

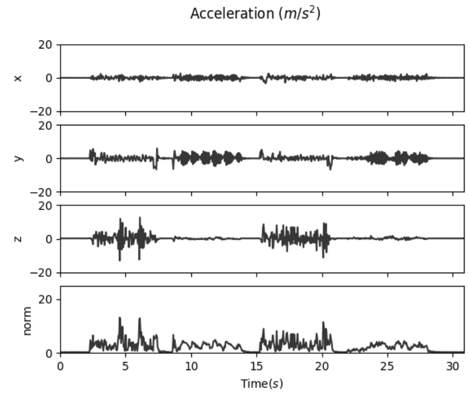

Figure 11. Vibration level of module (Normal, 50cm)

Fig. 6 ~ Fig. 11 is a graph showing the vibration levels generated by the multi-sensor modules at speeds in the creep and normal modes at heights of 15 cm, 30 cm, and 50 cm.
First, comparing the operation modes at the same height, as shown in the graph, it was confirmed that the vibration level was clearly lower in the creep mode. If you always operate in Creep mode, you can maintain higher accuracy, but since you can't determine anything at the disaster field, you should be able to maintain the best accuracy even in Normal mode.
In order to compare the vibration level according to the operation mode at the same height based on 30 cm, the ratios are tabulated together (table. 1).

Mount height	Creep		Normal	
	A(m/s²)	ratio	A(m/s²)	ratio
15cm	3.59	0.68	9.56	0.83
30cm	5.29	1	11.57	1
50cm	6.68	1.23	13.19	1.14

Table 1. Experimental results by height

Looking at Table 1, it can be seen that the vibration level at 15 cm in creep mode is clearly low. However, when looking at the ratio in Normal mode, a larger level of vibration change was detected than in the case of 30 cm. And at 50cm, the largest vibration level was detected in both creep mode and normal mode.
The height cannot be selected solely by the vibration level. It is necessary to check the scanning degree according to the height of the LiDAR sensor. The vertical field of view of the multi-sensor module LiDAR sensor is 45° (±22.5°), and when there are obstacles in the range, the desired scan data cannot be

obtained. Therefore, scan data were acquired at each height and compared.

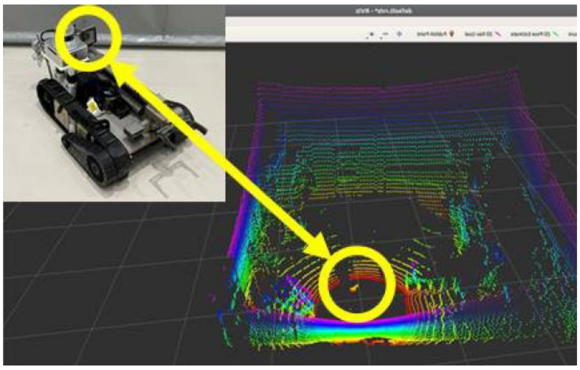

Figure 12. Scan data (15cm)

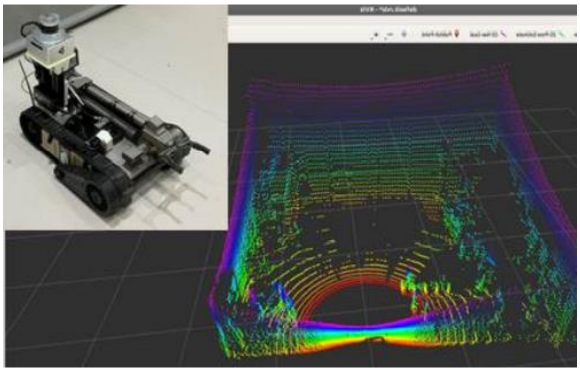

Figure 13. Scan data (30cm)

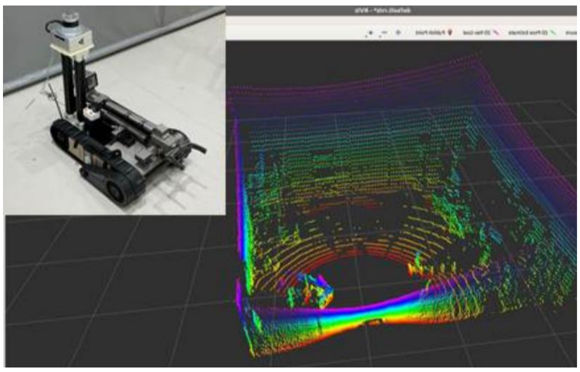

Figure 14. Scan data (50cm)

At 30 cm and 50 cm, it was confirmed that data were acquired without any major abnormalities (Fig 13 ~ Fig 14).
However, when the height of the LiDAR was 15 cm, it was confirmed that a gap in the scan data was generated by the camera and the lighting module mounted on the body of the Packbot as shown in Fig 11. Then, it can be seen that at least the height of the module must be higher than 30cm to fully acquire scan data in the field.

4. CONCLUSIONS

The purpose of the ongoing research is to conduct search and on-site monitoring using robots at actual disaster fields. Therefore, in this paper, a method for mounting the multi-sensor module including the LiDAR sensor in the iRobot Packbot to acquire the optimal scan data was studied. The following results were confirmed as a result of an experiment through the driving of the robot to select the mounting position and the height of the module.
First, in order to select the optimal location for mounting the multi-sensor module, a mounting point for mounting the radiation sensor on the arm of the robot with a high possibility and a mounting point for the vehicle body located on the side of the caterpillar tread motor were selected. The mounting point of the robot arm can freely adjust the direction angle and position of the multi-sensor module, but the stability is poor and the level of vibration transmitted when the robot is running is very large. Therefore, a body mounting point with greater stability was selected. In addition, an integrated mount was designed and manufactured to precisely connect itself and the multi-sensor module.
In addition, an experiment was conducted to select a height at which the multi-sensor module receives the minimum vibration and obtains the optimal scan data. Among the Packbot's three modes (Creep, Normal, and Fast), the height of the integrated mount was adjusted to three cases, 15 cm, 30 cm, and 50 cm in the Creep and Normal modes, except for the Fast modes with very severe vibration. And the degree of acquisition of scan data was confirmed at each height. As a result, it was confirmed that the vibration level was good at a height of 30 cm, and scan data were acquired without abnormality in all directions.
In this study, it was judged that it is best to mount the multi-sensor module at the mounting point of the Packbot body at a height of 30 cm. However, since the environment that always occurs is different, like the characteristics of the disaster field, it is judged that the operation mode and the height of the multi-sensor module should be able to change accordingly. In this study, a multi-sensor module mounting method was dealt with using Packbot, a caterpillar type robot, but the robot and the sensor to be mounted will be different depending on the purpose of use. It will be most important to find a suitable mounting method by considering the characteristics of the robot to be mounted and the characteristics of the sensor to be used.
Therefore, this study can be used as a prior study for many studies that want to install sensors and operate robots at disaster fields.

ACKNOWLEDGEMENTS

This research outputs are the part of the project “Disaster Field Investigation using Mobile Robot technology (II)”, which is supported by the NDMI (National Disaster Management research Institute) under the project number NDMI-MA-2022-06-02. The authors would like to acknowledge the financial support of the NDMI.

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