River Levees Monitoring Using Three Dimensional Laser Point Clouds with SLAM Technology

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Abstract. In recent years, record rainfalls have frequently occurred due to global warming, and river patrols and inspections are becoming increasingly important to prevent large-scale disasters such as levee breaks. The purpose of this paper is to introduce an IoT-based surveying method termed Simultaneous Localization and Mapping (SLAM) for river patrols and inspections. SLAM estimates the position of the technology itself and creates an entire map at the same time. Specifically, by performing the river patrols and inspections using SLAM technology with backpack-type LiDAR sensors, we could obtain the three-dimensional coordinate data of the levee at low cost. We have developed a monitoring method to quantitatively identify the locations of river levee deformations. We can obtain a high density of 56.5 million points with the LiDAR and present the accuracy of three-dimensional levee reproducibility using SLAM technology. In this paper, we demonstrate the usefulness of the LiDAR with SLAM technology based on monitoring data.

Keywords: River inspections · Three-dimensional laser point group · SLAM · Drone

1 Introduction

In recent years, record rainfalls have frequently occurred due to global warming, and river inspection to understand local situations has become more important for preventing large-scale disasters, such as levee breaches. In Japan, in 2017 and 2018, river levees managed by central and prefectural governments broke, causing severe damage. In these disasters, it became clear that even a single breach in a river levee, which is a linear structure, can cause serious damage. Considering that the frequency of rainfalls exceeding 50 mm per hour is increasing, it is even more important to carefully check the soundness of

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the levees over significant distances. However, the paucity of engineers and financial resources on the national and local government levels has become serious, and it is difficult to perform detailed levee inspection. Furthermore, the current levee inspection data are qualitative from visual inspection, and soundness is judged based on engineer experience. Overall, sufficient measures have not been taken to prioritize the necessary points.

Therefore, efficiently acquiring 3D data for levees by drone survey has attracted attention in recent years. This method makes it possible to quantitatively identify the changes that have only been understood qualitatively thus far. There are two methods of acquiring 3D data by drone survey: using digital images or using a laser scanner. The latter method has been expected to be effective for river levees because it requires less labor to install control points in the target area to be surveyed compared to the former method, which uses digital images. However, the self-positioning accuracy during drone surveys depends on the reception environment of GNSS, and sometimes, high-precision surveying cannot be expected depending on the time and place. Another issue is that if a drone is equipped with a heavy measurement device such as a laser, the flight time is limited to several tens of minutes due to the battery life, making it difficult to monitor a large area efficiently.

On the other hand, laser surveying methods implementing simultaneous localization and mapping (SLAM) technology, which has been practically applied in vehicle autonomous driving technology in recent years, are currently receiving attention. SLAM is a generic term for technologies that perform self-location estimation and whole map creation simultaneously. For an autonomous vehicle to recognize a place for the first time, it must create a map based on the information obtained while moving and estimate its own position on the map, and SLAM is used for this application. Because the system configuration is simple, 3D laser surveying while walking can be realized by combining it with a portable laser scanner. By combining this technology with the current patrol and inspection work, it is expected that 3D coordinate data for levees can be easily acquired and the technology for grasping the deformed portion of the river levee in real time can be realized. However, the deformation grasping technology of river embankment by combination of this SLAM and laser survey has not yet been generalized.

Against this background, this paper summarizes the advantages and disadvantages of 3D laser point cloud acquisition technology given by the portable laser measurement system incorporating drone survey and SLAM and presents the possibility of future 3D river levee monitoring. Specially, a system equipped with a green laser scanner of wavelength 532 nm was used for drone surveys. Because green lasers have the ability to penetrate water, it is expected to be applied to the regular cross-section measurement of rivers. In addition, the method is also expected to be able to acquire continuous 3D data from above the ground surface to below the water surface, as it will be possible to perform surveys with the same degree of accuracy as compared to conventional surveys using near-infrared lasers. This study applies both technologies, which are expected to be put to practical use in the future, to concrete sites, and summarizes the problems concerning survey accuracy and convenience based on actual examples. Furthermore, in this paper, the detection of river structure deformation such as foot protection is also targeted as a method of using 3D data. These results are expected to contribute to the provision of useful data when applying the monitoring method by 3D data to river management in the future.

2 Outline of the 3D Laser Point Cloud Acquisition System for the River Levee

2.1 Overview of Drone Equipped with Green Laser

Figure 1 shows a drone equipped with a green laser scanner, Fig. 2 shows the green laser scanner, and Table 1 presents the scanner specifications. The scanner weighs 2.8 kg, and the drone can fly for approximately 30 min. The scanner has a scanning range of 300 m and a scan rate of 60,000 points/s. The drone is equipped with a GNSS system with ±10 mm horizontal and ±20 mm altitude positioning accuracy.

Fig. 1. Drone-mounted LiDAR system

Fig. 2. Scanner

Table 1. Specifications of drone-mounted LiDAR

Laser wavelength	532 ± 1 nm
Laser pulse rate	60,000 Hz
Scan speed	30 scan/s
Beam divergence	0.3 mrad
Weight	2.8 kg

2.2 Outline of Portable Laser Measurement System

Figure 3 shows the portable laser measurement system tried in this research, and Table 2 details the system characteristics, including the specifications of the laser scanner. Here, we attempted measurements using two measurement systems with different self-position survey methods. One used SLAM, and the other used GNSS and an Inertial Measurement Unit (IMU). We call these survey method A and B, respectively. The lasers used were all in the near infrared wavelength range.

(a) Survey method A (b) Survey method B

Fig. 3. Overview of the portable laser scanner

Table 2. Specifications of the portable laser measurement system

	Survey method A	Survey method B
Maximum scope of laser measurements	80–100 m	100 m
Laser scan rate	300,000 Hz	700,000 Hz
Self-positioning method	SLAM	IMU + GNSS

3 Measurement Results

3.1 Overview of Measurement Site and Work

Figure 4 shows the site situation where the 3D laser point cloud was acquired. The measurements were taken in the 1.2 km portion denoted by the red line in the figure. The drone conducted measurements at an altitude of 50 m above ground, with a side lap of 75% and a flight speed at 2.5 m/s. Using the portable drone measurement system, the measurement was completed in about 90 min on foot for the range shown in Fig. 4. On the other hand, the drone flew 5 courses over approximately 120 min. Although the difference in the time spent for measurement was not significant, the former had the advantage of easy on-site assembly, convenience that could be taken by walking, and has the advantage of not requiring specialized flight skill training like the latter.

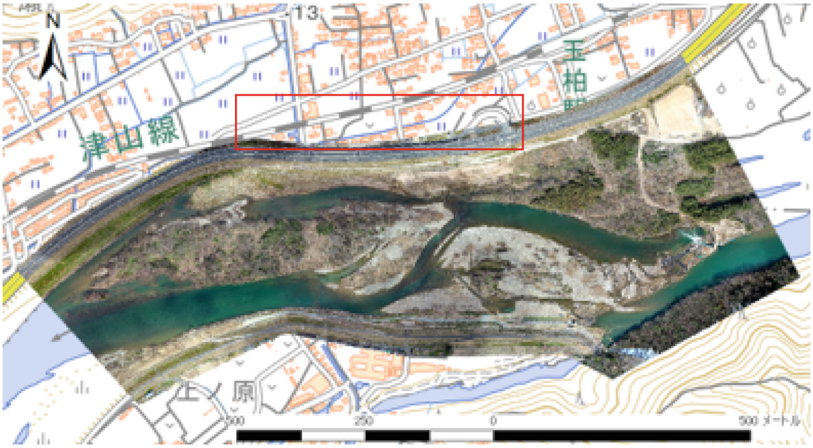
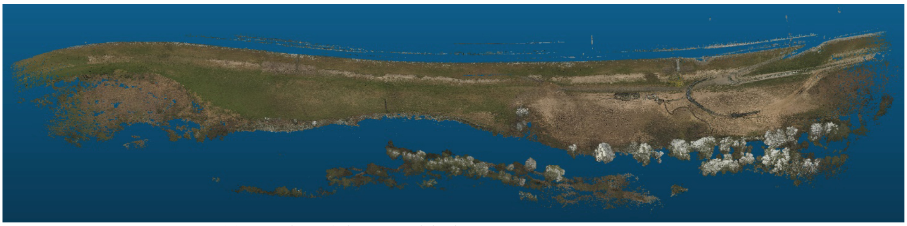


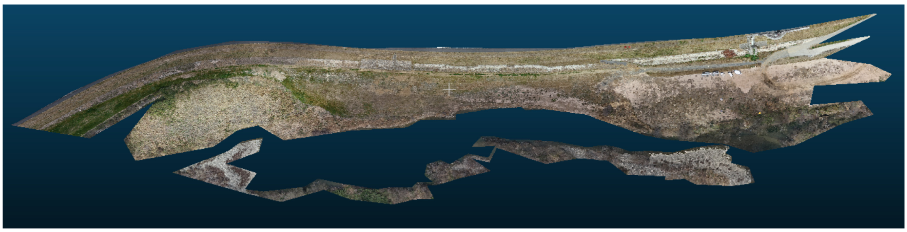
Fig. 4. Measurement site

3.2 Results of 3D Model Creation from Measurement Data

Figure 5 shows the river levee reproduction results obtained by survey method A. The laser point cloud obtained by the drone was trimmed according to the shape of the laser cloud obtained by the portable laser measurement system. The point density in the figure consists of 25.3 million points for the drone and 56.5 million points for the portable laser measurement system. In both cases, the levee can be reproduced with a high density of points. Figure 6 shows a slope that was reproduced using the portable laser measurement system on foot. Because obtaining measurements by walking on the inside of the levee is easy, it is possible to understand the sluice gate shape in detail, unlike the measurement from a drone at an altitude of 50 m above ground.



(a)Results of the portable laser measurement system



(b)Results of the drone survey

Fig. 5. Results of reproduction by laser point cloud

Fig. 6. Laser point cloud obtained by on-foot measurements on the inside of the levee using the portable laser measurement system

3.3 Accuracy Verification Results

Table 3 is a comparison of the survey results using the total station (TS) with the drone survey results, using the verification points installed within the measurement range. There are five verification points, and RMSE is the root mean square error of these. Both the X and Y planes and the elevation indicated by Z in the table are within ±50 mm of the average or RMSE with respect to the TS result.

Table 3. Drone survey accuracy verification results

(units: mm)	X	Y	Z
Average difference	0.0	13.0	−8.0
RMSE	40.0	15.0	27.0

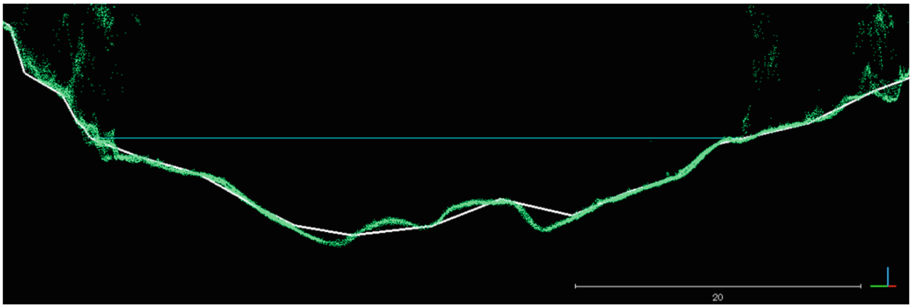
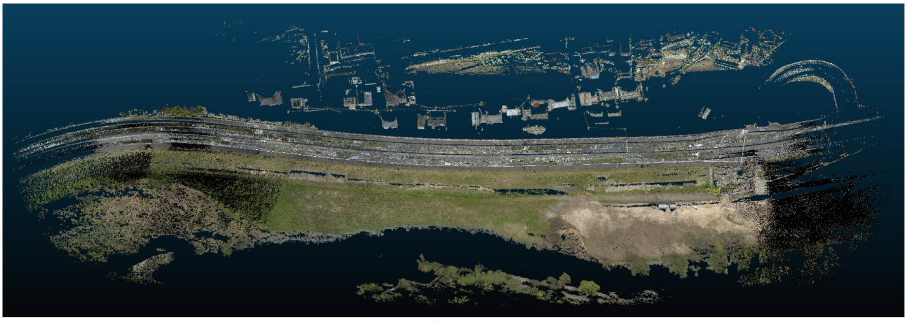


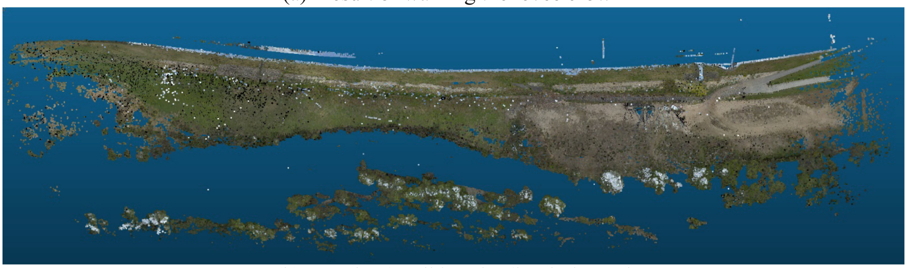
Fig. 7. Riverbed measurement results by drone survey (Blue solid line represents the water surface).

Figure 7 shows the results of measuring the riverbed by leveraging the characteristics of the green laser. The green point clouds in the figure is the measurement data by the laser, and the white solid line is the measurement result by bathymetric survey. By the way, the water depth of the cross-section survey diagram was 1.9 m. The water depth that can be measured depends on the transparency, but it was shown that at this site, the shape can be measured with almost the same accuracy as the white solid line up to a water depth of approximately 2.0 m.

In the measurement using the portable laser measurement system, the linearly structured levee was divided into several sections, and the measured data were overlaid without installing landmarks. For survey method A, the accuracy of integrating the 3D data obtained by continuously walking the entire 800 m section (Fig. 4) and the data obtained by in 150 to 200 m section increments was verified. Moreover, for survey method B, the accuracy of the measurement data obtained by walking the levee crown and the measurement data obtained by walking the flood-channel were both verified. Figure 8 shows the measurement results of survey method B, and Table 4 shows the accuracy results of each measurement data compared with the drone survey accuracy verification results.



(a) Result of walking the levee crown



(b) Result of walking the flood-channel

Fig. 8. Reproduction results from survey method B

For the two data collection methods used for survey method A, a difference in accuracy of about 0.2 m was observed. This is thought to be due to an issue with the SLAM technology whereby it accumulates errors. Moreover, for survey method B, a difference in accuracy of about 0.2 m was observed in places with no noise, such as sidewalks, and places with a significant noise due to vegetation, such as the flood channel. But it was found that even with the self-positioning measurement using only SLAM, the same degree of accuracy was obtained as that using GNSS and IMU. Hence, 3D data can be acquired with a lower-cost hardware configuration by dividing the measurement area into sections and conducting measurements in consideration of SLAM features.

Table 4. Accuracy verification results for survey methods A and B of the portable laser measurement system

(units: m)	Survey method A		Survey method B	
	Walk sections	Continuous walking	Levee crown	Flood channel
RMSE	0.31	0.49	0.33	0.50

4 Conclusion

In this study, we attempted to measure a river levee using a portable laser scanner and a drone. As methods for 3D reproducing the shape of it. The former method does not depend on the accuracy of GNSS positioning by introducing SLAM technology, and the latter uses a green laser that can be applied to riverbed measurements. Both methods are expected to be applied for river inspections in the future. The usage of each method derived from the results of this research is presented as follows.

(1) The drone survey equipped with the green laser has the advantage that not only can the riverbed be measured, but also the levee shape can be reproduced with high accuracy. In river management, the accuracy required when measuring the levee height and shape is ± 50 mm, and this method met these requirements. Furthermore, the range that can be measured with one flight is several km, but changes in levee height from the riverbed can be monitored with high accuracy.

(2) Measurements using the portable laser scanner can obtain an accuracy of 0.3 m even with the method of self-positioning by SLAM which is a low-cost hardware configuration. Since the accuracy required for aerial laser surveying used in river management is 0.3 m, we proved that it can be used as simple and low-cost measurements instead of aerial laser surveying. In particular, we found that because 3D data of levees can be obtained by walking on the levee crown or slope, the detailed measurement of shapes such as sluice gates and foot protection were obtained at the level of accuracy required to detect deformations. In river management, the accuracy required for measuring river management facilities and permitted structures is ± 0.3 m. Therefore, the portable laser scanner is effective for measuring the deformation of river structures.

SLAM is known to have the problem of accumulating position estimation errors with walking, which was observed in this study; thus, it is necessary to further investigate this error when measuring long distances. In addition, measurement using a drone requires processes such as optimal trajectory analysis using GNSS and IMU data to calculate the flight trajectory after measurement, which can problematize real-time measurements and requires further investigation. In the future, we aim to identify solutions to the problems that arise in the practical application of portable laser measurements and laser drone surveys, including the development of high-density point cloud superposition technology.

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