Construction and Usage of Three-dimensional Data for Road Structures Using Terrestrial Laser Scanning and UAV with Photogrammetry

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Abstract –

In road maintenance, it is necessary to construct an environment that manages three-dimensional data and maintenance information for its effectivity and efficiency. The primary objective of this research is to support road maintenance work using three-dimensional data by combining point cloud data of terrestrial laser scanning and unmanned aerial vehicles (UAV) with photogrammetry. For on-site surveying, the limitations have been clarified. The first limitation is based on site circumstances. Passengers and cars use the road being surveyed during measurements. There are few berms and little space for setting a terrestrial laser scanning. In addition, locations where instruments can be placed are limited. It is difficult to perform the number of measurements necessary for acquiring point cloud data. The second limitation is the measurement range, given the specifications of the instrument functionality for pavement surveys. The experimental results indicate that the high-density measurement range is restricted to within an approximately 10-m radius.

Based on these limitations, the upside of a slope or a landform is surveyed using a camera mounted on a UAV. Point cloud data for these objects are constructed using photographs with SfM technology. SfM data and terrestrial laser scanning data are combined because three-dimensional data for bridge sides and lower works cannot be constructed. To evaluate the accuracy of three-dimensional data, we compare the three-dimensional data with its design conditions. The inaccuracy for the bridge is an effective length of 12 mm and an effective width of 19 mm and the three-dimensional data describes the structure of the bridge with high accuracy.

The three-dimensional data for the road structures could be used to develop a road maintenance management system that accumulates data and refers to the inspection results and repair information in three dimensions.

Keywords –

Point Cloud Data; Terrestrial Laser Scanning; Unmanned Aerial Vehicle; Road

1 Introduction

Roads must be safe and maintained in good condition. Maintenance management is an essential operation that must be carried out effectively for maintaining, repairing, and rehabilitating roads. If large-scale damage occurs to a road in an urban area and it cannot be used, many aspects of life may be affected. Thus, it is important to protect roads from large-scale damage and to carry out road maintenance in order to maintain services for the public. In addition, it is necessary to accumulate information produced during the entire life cycle of a road in order to analyze problems and solutions within a temporal sequence and to maintain roads strategically and effectively. In Japan, much road infrastructure was built over fifty years ago. Due to progressive deterioration in road infrastructure, ensuring proper maintenance of overall facilities to avoid potential problems is currently an important issue. In particular, in order to avoid or reduce substantial loss, deal with an emergency, prevent damage, perform emergency disaster control, and carry out disaster recovery, road administrators must maintain roads more efficiently. In current maintenance work, road administration facilities are represented on a two-dimensional map, which is not suitable for pothole repair, inspection, or annual overhaul. Locating and analyzing a position can be difficult when using such a map.

In road maintenance, it is necessary to construct an environment that manages three-dimensional data and maintenance information. A road management system comprises functions for planning, design, construction, maintenance, and rehabilitation of roads. A fundamental requirement of such a system is the ability to support the modeling and management of design and construction information, and to enable the exchange of such information among different project disciplines in an effective and efficient manner.

Engineers should be able to use three-dimensional data not only for virtually reviewing the design of a facility, but also for analyzing building operations and performance. Three-dimensional data tend to be applied to a particular phase of a construction project. Using three-dimensional data will thus improve the efficiency of operations and maintenance.

Dense point cloud data were generated using three and over pictures which taken same points [1], [2]. Agarwal et al. and Frahm et al. were constructed three-dimensional city by automated reconstruction [3], [4]. The three-dimensional point cloud data are constructed on the basis of the Structure from Motion (SfM) range-imaging technique of photogrammetry using video camera data. The accuracy of three-dimensional model by SfM were evaluated by several researches [5]. And, the generated point cloud data which measured the objects from several measurement points are integrated for representing the accurate objects. The integration method of point cloud data is iterative closest point method (ICP) [6], globally consistent registration method of terrestrial laser scan data using graph optimization [7], curve matching [8], [9], and automated registration using points curve [10].

The primary objective of this research project is to propose a road maintenance framework using three-dimensional point cloud data. A point cloud is a collection of data points defined by a given coordinate system. In a three-dimensional coordinate system, for example, a point cloud may define the shape of some real or created physical system. Terrestrial laser scanning [1], [2], and [3] and photogrammetry technologies are used to survey road structures. In road maintenance work, a mobile mapping system (MMS) is used, which generates point cloud data. In this research project, terrestrial laser scanning and photogrammetry by an unmanned aerial vehicle (UAV) are used. Three-dimensional data for the Shiraito Highland Way in Japan are constructed using point cloud data generated by terrestrial laser scanning. Shiraito Highland Way is approximately 10 km in length, and its elevation varies between 1000 m and 1400 m. The measuring range of terrestrial laser scanning on a road varies from approximately 10 m to 100 m. Point cloud data are combined using coordinate points. In addition, the data are used for road maintenance, taking into consideration data size and accuracy. Road maintenance information can be referenced at any three-dimensional point in the point cloud data. PhotoScan Professional (Agisoft) is used for SfM. This paper evaluates the accuracy of the usage of point cloud data by laser scanning and photogrammetry for road maintenance. For example, this method can be used to check potholes and surface irregularities on pavement that can be easily and quickly confirmed by management.

2 Usage of Terrestrial Laser Scanner and Photogrammetry of UAV Camera

There are a number of survey methods for constructing three-dimensional data using laser imaging detection and ranging (Lidar; laser profiler), laser-based photogrammetry, mobile mapping system, terrestrial laser scanning, and photogrammetry using a camera by UAV. Combining these survey methods according to site situations and structures enables surveys of civil infrastructure and construction of three-dimensional point cloud data. It is necessary to understand the characteristics and specifications of the specific measurement instruments and choose suitable point cloud data for a use case for a road maintenance site. In this research project, terrestrial laser scanning and UAV-based photogrammetry are used for usage scenes as shown in Figure 1.

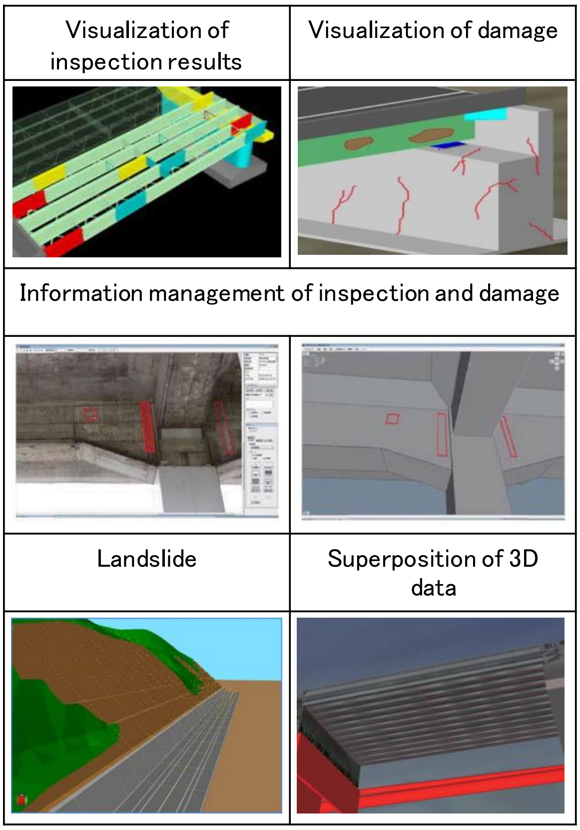

Figure 1. Usage scenes of three-dimensional data

2.1 Usage of Terrestrial Laser Scanner

A terrestrial laser scanner is set on a ground surface, and the laser component illuminates objects. A laser beam is reflected, and a return-beam detection device records two-way travel time, calculating the distance between the scanner and the object. As a result, point cloud data for an observed object are generated. When using terrestrial laser scanning, it is important to choose a location where the instrument can be set up easily. It is usually advantageous to overlook and survey the location when setting up the instrument.

Table 1 Characteristics of point cloud data by TLS and UAV photogrammetry

	Terrestrial Laser Scanner	UAV photogrammetry
Survey cost (time)	Expensive, but portable	Less expensive and small size
Measurement range	Narrow area	Wide area
Visible area	Visible area from point of terrestrial laser scanning	UAV flight area
Invisible area	Superior surface cannot be measured	Overhang area cannot be measured
Accuracy	A few millimeter	Depends on SfM software
Density of points	Extremely high	High
Distribution	Non-uniform	Depends on SfM software
Angle	10 to 90 degrees	Approximately 90 degrees
Measurement of edge	Exactly	Potentially inaccurate
Measurement of surface	Including noise	Including noise
Measurement of structure	Side surface can be measured	All surfaces can be measured
Noise	Including noise	Including noise
Reflected data	*xyz* coordinates value of local coordinate	*xyz* coordinates value of plane rectangular coordinate system

2.2 UAV Platform Camera

Point cloud data are generated by aerial photogrammetry using photographs or a video-output camera on a UAV. The data are generated using a SfM process [4], [5], and [6]. The characteristics of terrestrial laser scanning and UAV photogrammetry are represented in Table 1. They are analyzed with respect to time cost, measurement range, visible area, invisible area, accuracy, density, distribution, angle, measurement of edge, ground, and structure, noise, and enabled data.

3 Survey and Construction of Three-dimensional Data

Terrestrial laser scanning and UAV photogrammetry technologies are used to survey and generate road structures. Three-dimensional point cloud data for the Shiraito Highland Way in Karuizawa Village, Kitasaku County, Nagano Prefecture, Japan, are used.

In this paper, usage of point cloud data for road maintenance is proposed. If a road administrator possesses point cloud data for a MMS, the data are used for road maintenance. Usage of terrestrial laser scanning is more efficient for surveying narrow areas to check for cracks and holes in the pavement of a road. In the case of a landslide on the side of a road, using terrestrial laser scanning to survey the upside of a slope can be difficult. The reason is that terrestrial laser scanning has limitations for measuring the upside of a landform or slope occluded by such objects as trees or other vegetation and by the angle of incidence of the scanner.

3.1 Construction of Landform Data

Therefore, the upside of a slope or a landform is surveyed using a camera mounted on a UAV. Point cloud data for such objects are constructed using photographs employing SfM technology. Figure 2 depicts SfM data and laser scanning data for a slope. The point cloud data are constructed by combining SfM data with laser scanning data corresponding to 5000 random points between those data, as depicted in Figure 2. The constructed three-dimensional data were superposed for grasping the difference in temporal sequences. The data of 2017 and 2018 were used. The difference was calculated and represented using difference analysis function of Cloud Compare software as shown in Figure3. The lack of soil in slope was represented using blue color and was used for understanding the shape of cross section.

A terrestrial laser scanner is set on a ground surface, and the laser component illuminates objects. A laser beam is reflected, and a return-beam detection device records two-way travel time, calculating the distance between the scanner and the object. As a result, point cloud data for an observed object are generated. When using terrestrial laser scanning, it is important to choose a location where the instrument can be set up easily. It is usually advantageous to overlook and survey the location when setting up the instrument.

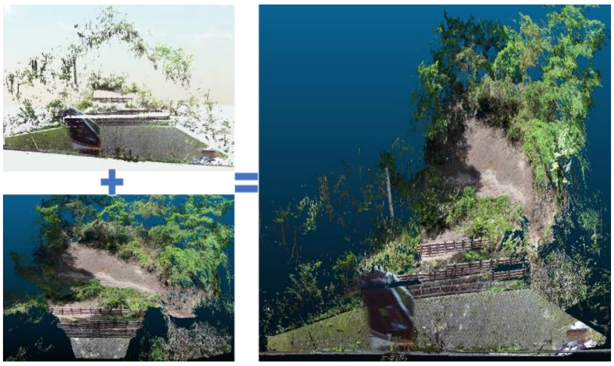

Figure 2. Fusion of three-dimensional point cloud data acquired by terrestrial laser scanning and UAV photogrammetry on slope

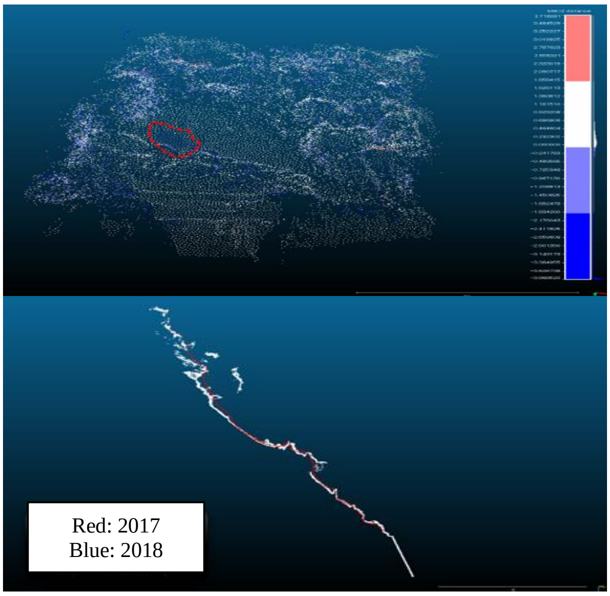

Figure 3. Difference of cross section in temporal sequences

3.2 Limitations for On-site Survey

According to the results of an on-site survey, limitations have been discovered. The first limitation is based on site circumstances. Passengers and cars pass by on the road being surveyed during measurement. There are few berms and little space for setting a terrestrial laser scanning, given the high slope on the Shiraito Highland Way. In addition, locations where instruments can be set are limited. Therefore, it is difficult to perform a number of measurements for acquiring point cloud data. It is necessary to pay attention to surveyors and instruments, and to determine measurement range and accuracy for the set of circumstances.

The second limitation is measurement range, given the specifications of instrument functionality for pavement surveys. According to experimental results, high-density measurement range is restricted to within an approximately 10-m radius, as depicted in Figure 4. It is necessary to perform a number of plural measurements for surveying wide-range pavement data. Figure 5 shows the three-dimensional data of road surface connected the thirteen laser scanning data of 10 m radius. The reference points such as trees and guard rails were set for data fusion. The data have about 300 m length and 208,375,900 points.

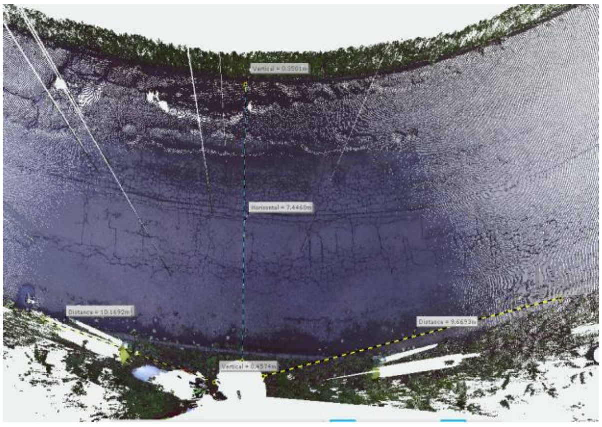

Figure 4. Point cloud data on road surface

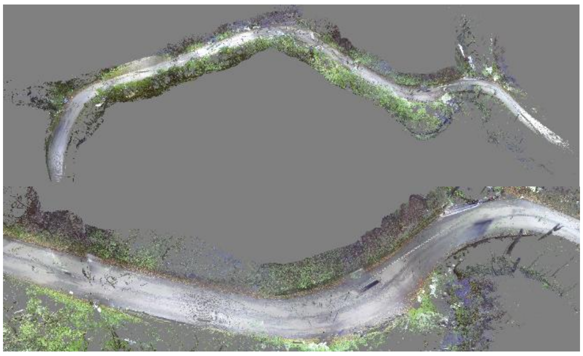

Figure 5. Three-dimensional data of road surface

3.3 Construction of Bridges

To construct the three-dimensional data for the upper and lower part of bridges, UAV aerial photogrammetry and terrestrial laser scanning measurements were performed for the Kashii River (Izumisano City) and Kimyuji River (Sennan City) in the south of Osaka Prefecture in November 2017. During the UAV aerial photogrammetry, the UAV flew at an altitude of 30 m, the movie was converted into pictures, and SfM processing was performed with PhotoScan to construct the three-dimensional data.

Figures. 6 and 7 depict examples of data fusion of terrestrial laser scanning and SfM data acquired by a UAV using the same method as described above.

Figure 6. Data fusion of terrestrial laser scanning and UAV in road and bridge

Figure 7. Data fusion of terrestrial laser scanning and UAV on a bridge

4 Accuracy Evaluation of Three-dimensional Data

4.1 Accuracy of UAV Photogrammetry Data

The accuracy of UAV photogrammetry data and constructed three-dimensional data were evaluated by assigning absolute coordinates from the global navigation satellite system survey to the three target points as reference points, and four verification points were used as shown in Figure 8. The accuracy is validated using root mean squared error with *xy* plane and altitude of *z* coordinate. RMSE is calculated using the true coordinate measured by GNSS (Pentax G3100-R2B) and point clouds. The root mean square error was 0.272 m in the *xy* direction and 0.261 m in the *z* direction (Table 2). Because the wind was strong at the time of the measurements, the fact that the aircraft and the camera were not stable affected the accuracy. For the terrestrial laser scanning, we targeted the Megata Bridge in Kashigawa River and the Warazuhata Bridge in Kinyuji River, the feature points of multiple-point group data measured from six places bridges from five places were matched, and thinning processing was applied to obtain one data point.

Figure 8. Target setting points

Table 2. Accuracy verification results for SfM data

Inaccuracy (m)	*xy* direction	*z* direction
Point A	0.199	0.349
Point B	0.232	0.082
Point C	0.414	0.211
Point D	0.185	0.120
Average	0.258	0.191
Root mean squared error	0.272	0.216

Table 3. Accuracy verification results for fusion data

Inaccuracy (m)	*xy* direction	*z* direction
Point A	0.035	0.033
Point B	0.011	0.009
Point C	0.010	0.008
Point D	0.043	0.047
Average	0.025	0.024
Root mean squared error	0.029	0.029

4.2 Accuracy of Fusion Data

The three-dimensional point cloud data obtained by SfM are measured from the air, and SfM data and terrestrial laser scanning data are combined because three-dimensional data for bridge sides and lower works cannot be constructed. The accuracy of terrestrial laser scanning data is higher than that of SfM data, and therefore duplicate SfM data are deleted before combining. According to Cloud Compare, we can combine 50,000 characteristic points for each type of data with reference to each other type of data and describe the side and bottom works of bridges that could not be acquired by UAV aerial photogrammetry as three-dimensional data. The fusion data of Warazuhata Bridge were evaluated by root mean squared error in Table 3. The root mean squared error was 0.029 m in the *xy* direction and 0.029 m in the *z* direction. It represents high accuracy of the three-dimensional data combined by terrestrial laser scanning data and UAV photogrammetry data. To evaluate the accuracy of three-dimensional data, we compare the point cloud data of the Warazuhata Bridge with its design conditions. The bridge length is 22.20 m and its width is 4.00 m, whereas the bridge length from the point cloud data is 22.212 m and its width is 4.019 m. Therefore, the inaccuracy for the bridge is an effective length of 12 mm and an effective width of 19 mm (Figure 9) and the three-dimensional point cloud data describes the structure of the bridge with high accuracy.

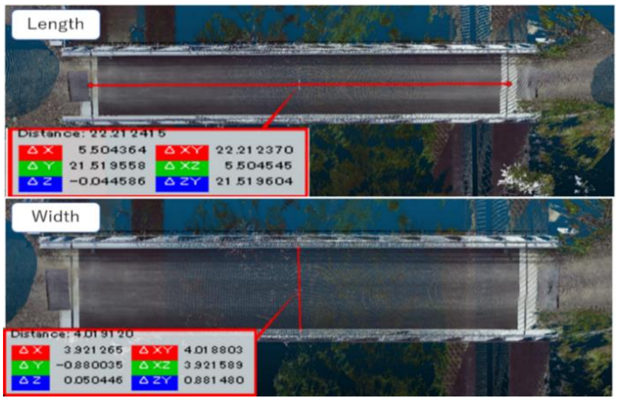

Figure 9. Length and width based on the combined point cloud data for Warazuhata Bridge

5 Proposal of Road Maintenance Information System Using Three-dimensional Data

The three-dimensional point cloud data for the road pavement surface and the bridge could be used to develop a road maintenance management system that accumulates data and refers to the inspection results and repair information in three dimensions.

An information system for road maintenance is proposed in this research project. This chapter discusses the information system, which uses point cloud data based on the definition of an information system.

By definition, an information system collects, processes, transfers, and utilizes information in its own domain. Figure 10 depicts the definition of a road maintenance information system using point cloud data.

A road maintenance system was considered based on the definitions within an information system. The road maintenance system can link inspection results and recondition information with the point cloud data for display, storage, and reference, facilitating the management of road cracks and areas for repair. In future work, point cloud data will be used to identify changes in the shape and condition of damage through spatial and temporal management.

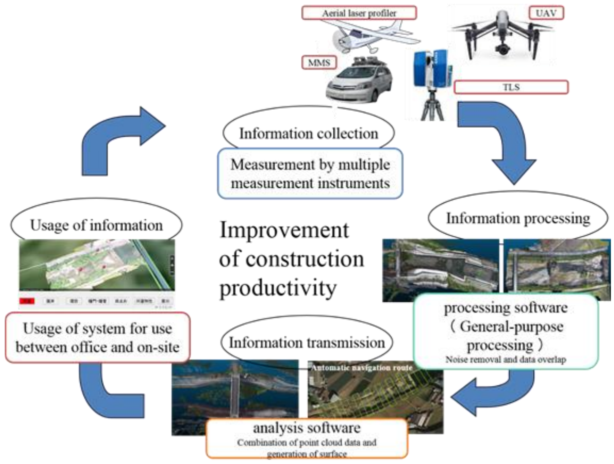

Figure 10. Definition of road maintenance system

5.1 Information Collection

Point cloud data for road infrastructure are collected using terrestrial laser scanning and UAV-based photogrammetry. In addition, maintenance and operation data, such as for inspection, rehabilitation, and repair, are collected on-site for the system.

5.2 Information Processing

Point cloud data generated by terrestrial laser scanning contain noise data concerning trees and vegetation on a road. In information processing, such objects should be removed in order to represent road structures accurately. terrestrial laser scanning's survey range is confined to the visible range and the scan range of the scanner; therefore, it contains blind spots that are not represented by the point cloud data cloud. Accordingly, surveyors need to move the scanner to multiple locations across a number of points in time. UAVs can acquire photographs or videos in-flight. Such visual records are used for SfM software and translated point cloud data. In addition, the point cloud data are colorized for visualization.

5.3 Information Transmission

Terrestrial laser scanning and UAV-based photogrammetry each have distinct characteristics with respect to survey time cost, scan range, and accuracy. Wide area and high precision point cloud data are generated by combining each set of data units. In addition, in this process, structural members and surface data, such as a triangulated irregular network, are extracted and generated in accordance with the purpose of usage. Furthermore, it is also possible to compare two different temporal data units for analysis.

5.4 Usage of Information

In this research project, instead of a surface model, point cloud data are used for road maintenance. A road maintenance information system is proposed, which has functions for detecting cracks and superimposing photographs based on point cloud data. In addition, a function is needed for reflecting inspection and repair events that have been represented on a two-dimensional map displayed on a smart device onto three-dimensional point cloud data on-site.

In the road maintenance system, the inspection result and repair information can be linked with three-dimensional point cloud data and displayed, stored, and referenced. It is easy to detect road cracks and spots in need of repair, as depicted in Figure 10. In addition, it is possible to determine changes in shape and damage using temporal management of point cloud data.

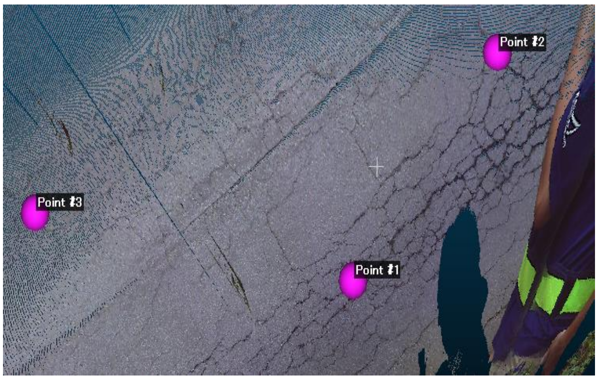

Figure 11. Repair information linked with three-dimensional point cloud data

6 Conclusion

In this research project, point cloud data for road infrastructure have been surveyed using terrestrial laser scanning and UAV photogrammetry for road maintenance. For on-site surveying, the limitations of these methods have been clarified. The first limitation is based on site circumstances. Passengers and cars use the road being surveyed during measurements. There are few berms and little space for setting a terrestrial laser scanning, given the high slope on the road. In addition, locations where instruments can be placed are limited. Therefore, it is difficult to perform the number of measurements necessary for acquiring point cloud data. The surveyors, instruments, and measurement range and accuracy of the conditions should be considered. The second limitation is the measurement range, given the specifications of the instrument functionality for pavement surveys. The experimental results indicate that the high-density measurement range is restricted to within an approximately 10-m radius. Thus, multiple measurements must be taken for surveying wide-range pavement data. Based on these limitations, in this work, the upside of a slope or a landform is surveyed using a camera mounted on a UAV. Point cloud data for these objects are constructed using photographs with SfM technology. SfM data and laser scanning data are used for slopes. The point cloud data are constructed by combining SfM data with laser scanning data corresponding to 5000 random points between these data.

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