Road Maintenance Management System Using 3D Data by Terrestrial Laser Scanner and UAV

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Abstract –

In road maintenance, it is necessary to construct an environment that manages 3D data and maintenance information for its effectivity and efficiency. Engineers should be able to use 3D data not only for virtually reviewing the design of a facility, but also for analyzing building operations and performance. Using 3D data will thus improve the efficiency of operations and maintenance.

The primary objective of this research is to support road maintenance work using 3D data by combining point cloud data of terrestrial laser scanning (TLS) and unmanned aerial vehicles (UAV) with photogrammetry. TLS and photogrammetry technologies were used to survey pavement, landform, and bridge of road structures.

This research evaluated the accuracy of the usage of point cloud data by TLS and photogrammetry for road maintenance. This method can be used to check potholes and surface irregularities on pavement that can be easily and quickly confirmed by management. To evaluate the accuracy of 3D data of the bridge, we compare the 3D data with its design conditions. The 3D data describes the structure with high accuracy.

The 3D data could be used to develop a road maintenance management system that accumulates data and refers to the inspection results and repair information. The 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. The prototype system was developed using Skyline Terra Explorer Pro. It was visualized constructed 3D data on temporal sequence.

Keywords –

Three-dimensional Data; Point Cloud Data; Terrestrial Laser Scanning; Unmanned Aerial Vehicle; Road Maintenance; Information System

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. 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 2D 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.

There are many reported cases of damage to aging road structures. Existing structures are generally maintained rather than rebuilt, but blueprints and completion drawings may be unavailable for road structures that have been in service for a long time, and existing drawings may no longer reflect the current situation, hindering inspections and repairs [1]. To realize appropriate road maintenance, it is important to share information among all stakeholders, and easily shared 3D data with high visual fidelity are effective means toward this end. 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.

With the introduction of unmanned aerial vehicles (UAVs) and terrestrial laser scanners (TLS) in the "i-Construction" policy being promoted by the Japanese Ministry of Land, Infrastructure, Transport and Tourism, there will be increased use of 3D data in the future. Dense point cloud data were generated using three and over pictures which taken same points [2], [3]. Agarwal et al. and Frahm et al. were constructed 3D city by automated reconstruction [4], [5]. The 3D 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 3D model by SfM were evaluated by several researches [6]. 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) [7], globally consistent registration method of terrestrial laser scan data using graph optimization [8], curve matching [9], [10], and automated registration using points curve [11].

However, there are outstanding issues related to TLS measurements. In particular, selection of appropriate measurement positions is difficult, data loss can occur, and increasing the number of measurements to obtain more detailed data increases measurement and data-processing times. Further, maintenance management systems for use of the generated 3D data are still under development. Data processing software differs according to the equipment used, and data storage can be complex.

In this study, we performed TLS, UAV, and camera measurements on road pavement, bridges, and slopes with the aim of realizing 3D data for road maintenance. We also devised a method for constructing 3D data for structures lacking existing drawing information. To do this, we attempted measurement methods and data generation for constructing highly accurate 3D data for a bridge from a small number of measurements. We also investigated functions for collectively managing the generated 3D data and visualizing results of inspecting the 3D data.

2 Use Cases of 3D Data

There are a number of survey methods for constructing 3D 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 3D 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. Usage scene 1 visualization of inspection results; Usage scene 2 visualization of damage on the structures; Usage scene 3 information management of inspection and damage; Usage scene 4 landslide; Usage scene 5 superposition of 3D data.

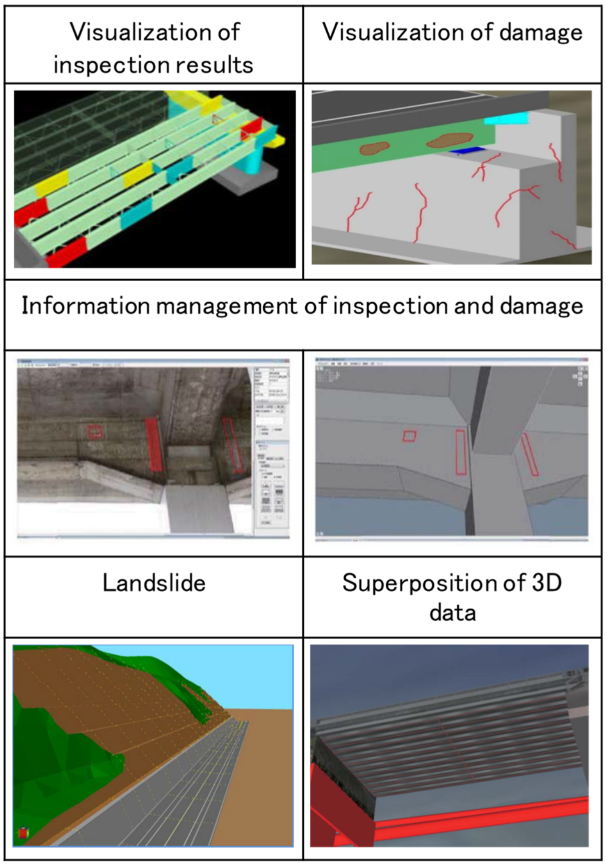

Figure 1. Usage scenes of 3D data

3 Measurement and Construction of On-site 3D Data

3.1 3D Data Measurements Using Multiple Devices

In addition to TLS and UAV images as used in our previous study [12], here we used SfM technologies to generate point-cloud data from camera images and combined the images and data to generate high-density 3D data. Equipment used were a laser scanner (Focus

3D X 330; FARO), a UAV (Inspire2 with mounted Zenmuse X5S camera; DJI), and a handheld camera (GoPro Hero6 Black; GoPro, Inc.).

3.2 Pavement Surface Measurement and 3D Data Construction

We performed TLS measurements in September 2019 on paved surfaces along the Shiraito Highland Way in Karuizawa, Nagano Prefecture. The Focus 3D X330 can perform high-density measurements of road surfaces over a range of about 10 m [12], so we measured 16 points at 20-m intervals based on an approximate 10-m radius, and constructed 3D data using the FARO SCENE data processing software. Figure 2 shows the 3D data of the pavement. To reduce the burden of image-joining tasks, we used triangular cones at 10-m intervals as targets during measurements. This reduced time required for joining tasks as compared with data construction in our previous study [12], but it was difficult to specify points in the 3D point-cloud data. In future studies we will investigate use of planar objects such as spheres and cylinders as feature points when combining images.

In combination with data collected in 2018, 3D data were constructed for a road length of about 580 m in Figure 3. The average error for point-to-point distances for joining locations in the measurement data was 4.7 mm, which was better than the accuracy of 8 mm required in this study. As reference points within the measurement range, we used slopes calculated from horizontal and vertical distances listed in the Shiraito Highland Way Toll Road Reference Point Survey and measured points near the reference points in the point cloud data. Comparing the obtained gradients showed differences of less than 0.5%, indicating that the gradients were essentially the same.

Figure 2. Joined road surface data

Figure 3. Joined FY2018 and FY2019 3D measurement data

3.3 Slope Measurement and 3D Data Construction

UAV measurements was performed in September 2019 on slopes of the Shiraito Highland Way in Karuizawa, Nagano Prefecture. Video images were extracted at 1-s intervals, and used the Metashape software package (Agisoft) to perform SfM processing on a computer with an Intel Core i9-9900X CPU, an NVIDIA GeForce RTX2070 GPU, and 64 GB RAM. The open-source point-cloud editing software package CloudCompare was used to overlay data constructed in FY2017, 2018 [12], and 2019 and performed differential analysis. Figure 4 shows the results, which indicate that the amount of accumulated sediment in the upper part decreased and that in the lower part increased in 2018 as compared to 2017, suggesting that sediment is flowing downward over time.

3.4 Bridge Measurement and 3D Data Construction

Measurements using TLS, UAV, and on-ground cameras were performed in July 2019 at the Warazuhata Bridge in Sennan, Osaka. We performed TLS measurements at six locations around the bridge, and combined data measured from pairs of diagonal points across the bridge with the 3D data constructed by SfM processing of images captured by the UAV and the camera in Figure 5. The upper figure of Figure 5 shows 3D data created by combining TLS and UAV photogrammetry. The lower figure shows 3D data created by combining data created from TLS and handheld camera images. As a result, we were able to provide data for the superstructure and the abutment sections, which were missing in the 3D data constructed from the two-sites TLS measurements, and we could construct 3D data showing the bridge length and width. For the bridge length and width, we compared measurement results in the 3D data constructed from the six TLS measurements with design specifications from the Kishiwada Civil Engineering Office and with on-site measurements. Table 1 shows the results, which suggest that the 3D bridge data constructed in this study has a

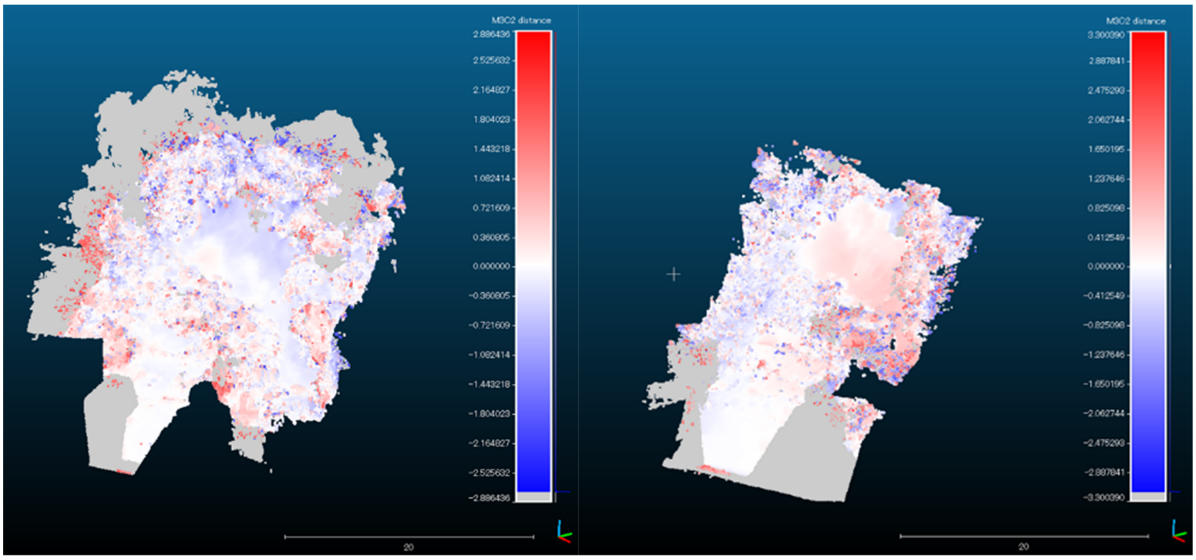

Figure 4. Differential data for (upper) FY2017 and 2018 and (lower) 2018 and 2019

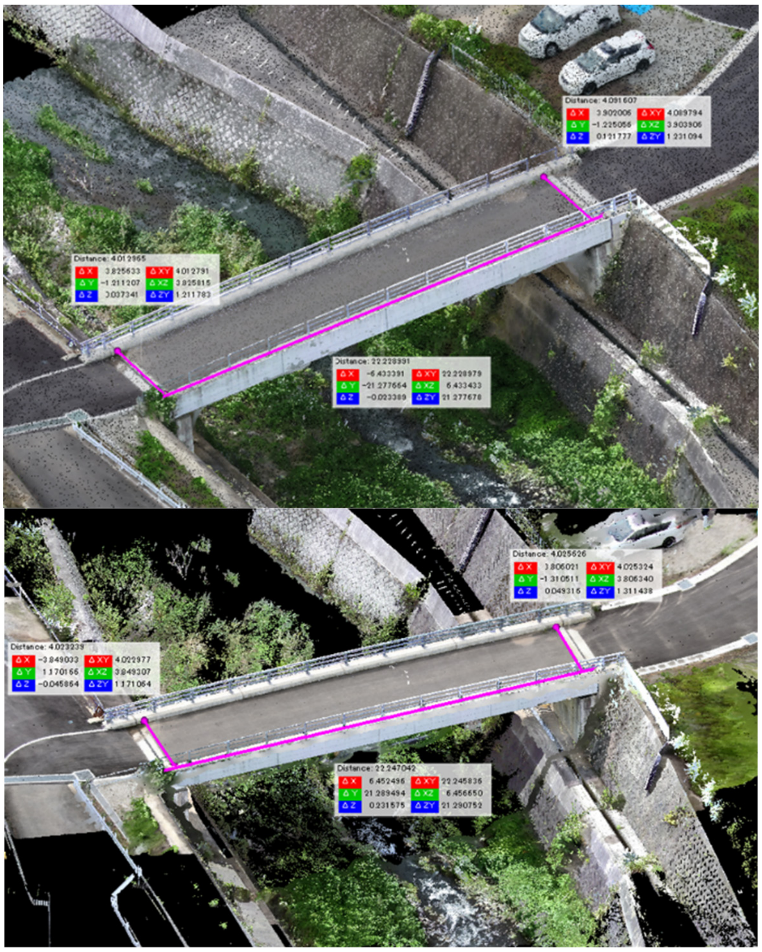

Figure 5. (Upper) 3D data combining TLS and UAV photogrammetry and (lower) 3D data combining data created from TLS and handheld camera images

level of development of around 200 as indicated in the level of development for three-dimensional model in civil engineering (Draft) [13].

The time required for TLS measurements at six locations was about 2 hours, while the time for two locations was about 40 min. In contrast, the UAV photography time was about 15 min including preparation and GoPro shooting time was about 10 min, suggesting their potential for shortening on-site measurement times.

To construct 3D data with location information, in November 2019 we took a series of photographs with a GoPro camera capable of acquiring location information at an unnamed bridge in Niigata City, Niigata Prefecture, and performed SfM processing to construct 3D data in Figure 6. Selecting an arbitrary point in the 3D data shows the latitude and longitude for that point. The data do not have the ground control points. The data were set using the latitude and longitude of GPS of GoPro camera. We arranged it using aerial photograph.

Table 1. Comparison of measured lengths and widths

	Length (m)	Width (m)
Design specifications	22.200	4.000
On-site measurement	22.253	4.025
TLS (6 locations)	22.258	4.013
TLS (2 locations) and UAV	22.229	4.052
TLS (2 locations) and camera	22.247	4.024

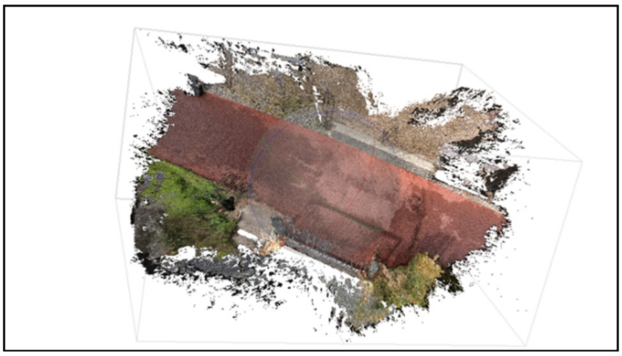
Figure 6. 3D data from SfM processing for a bridge

4 GIS Visualization of 3D Data

The 3D 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 7 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.

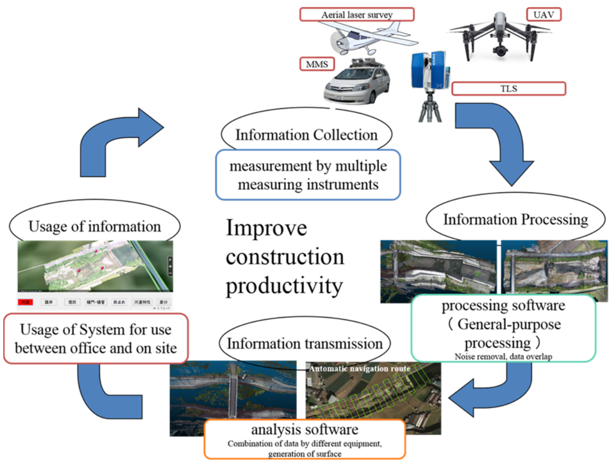

Figure 7. Definition of road maintenance management system

4.1 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.

4.2 Information Processing

Point cloud data generated by TLS 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.

4.3 Information Transmission

TLS 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.

4.4 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 3D point cloud data on-site. In the road maintenance system, the inspection result and repair information can be linked with 3D point cloud data and displayed, stored, and referenced. It is easy to detect road cracks and spots in need of repair. In addition, it is possible to determine changes in shape and damage using temporal management of point cloud data.

We arranged the constructed 3D data using absolute GIS coordinates, storing these data with corresponding inspection results. This should allow road managers to better grasp topographical information for the surrounding area and to store positional coordinates for stored locations, leading to more efficient maintenance. By road managers performing regular inspections and confirming and comparing 3D data before and after a disaster, this function can be applied to grasping the damage situation. We used Terra Explorer Pro (Skyline Software Systems) as GIS software for displaying 3D data. Absolute coordinates for road pavement and slopes were given using the "Align two clouds by picking (at least 4) equivalent points pairs" function in Cloud Compare and displayed on a 3D map. Because 3D data for the Warazubata Bridge did not have position coordinates and thus could not be displayed at an arbitrary position, we manually set latitudes, longitudes, and altitudes in reference to aerial photographs. Regarding the 3D data for the unnamed bridge in Niigata, comparing bridge positions on Google Earth showed no significant differences for latitude and longitude, but there were large displacements for altitudes, causing the 3D data in the map display to appear as if floating in air. We therefore corrected positions in reference to aerial photographs. Displaying the 3D data on a map confirmed cracks in the paved surface, and 3D data from two different periods could be displayed in Figure 8 and 9. These figures show the registration function of the system for accumulating the inspection and damage information on the point cloud data.

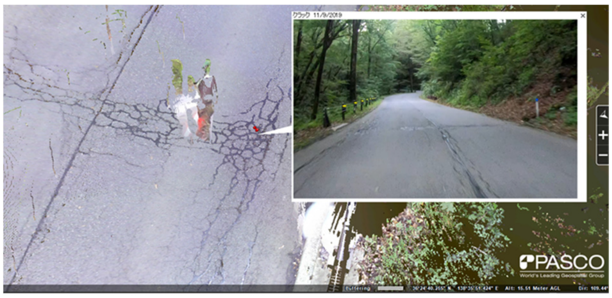

Figure 8. 3D Road surface data display in the system

Figure 9. 3D land form data display in the system

5 Conclusion

In this study, we investigated a system for using TLS, UAV, and cameras to construct 3D data for road pavement, slopes, and bridges. The system provides absolute coordinates, displays them on a 3D map, and can store and reference inspection results at any location. Future tasks will include improving the efficiency of overlaying 3D data constructed in different years by setting positioning points during measurements, and creating 3D data with positional information for measurements of sediment runoff.

Acknowledgements

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References

[1] Ministry of Land, Infrastructure, Transport and Tourism, *Proposals for implementation of measures against road deterioration*. 2014.

[2] Furukawa, Y. and Ponce, J., Accurate, dense, and robust Multiview stereopsis, *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 32(8): 1362-1376, 2010.

[3] Hirschmuller, H., Stereo processing by semiglobal matching and mutual information, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 3(2): 328-342, 2008.

[4] Agarwal, A., Snavely, N., Simon, I., Seitz, S. and Szeliski, R., Building Rome in a day, In *ICCV09*, pages 72-79, 2009.

[5] Frahm, J.M., Fite-Georgel, P., Gallup, D., Johnson, T., Raguram, R., Wu, C., Jen, Y.H., Dunn, E., Clipp, B., Lazebnik, S. and Pollefeys, M., Building rome on a cloudless day, In *ECCV10*, pages 368-381, 2010.

[6] Remondino, F., Del, P.S., Kersten, T.P. and Troisi, S., Low cost and open source solutions for automated image orientation – a critical overview, *Lecture Notes in Computer Science*. 7616, pages 40-54, 2012.

[7] Besl, P. J. and McKay, H. D., A method of registration of 3-D shapes, *IEEE Transaction Pattern Analysis and Machine Intelligence*. 14(2): 39-256, 1992.

[8] Pascal, W. H., Wegner, J. D. and Schindler, K., Globally consistent registration of terrestrial lase scans via graph optimization, *ISPRS Journal of Photogrammetry and Remote Sensing*. 109: 126-138, 2015.

[9] Grune, A. and Akca, D. Least squares 3D surface and curve matching, *ISPRS Journal of Photogrammetry and Remote Sensing*. 59: 151-174, 2005.

[10] Yang, B. and Zang, Y., Automated registration of dense terrestrial laser-scanning point clouds using curves, *ISPRS Journal of Photogrammetry and Remote Sensing*, 95: 109-121, 2014.

[11] Yang, B., Dong, Z., Liang, F. and Liu, Y., Automated registration of large-scale urban scene point clouds based on semantic feature points curves, *ISPRS Journal of Photogrammetry and Remote Sensing*. 113: 43-58, 2016.

[12] Kubota, S. and Ho, C.Y., Creation of three-dimensional data for road maintenance using several measurement instruments. *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics*, 31(6): 867-875, 2019.

[13] The committee for standardization of civil infrastructures, *The level of development for three-dimensional model in civil engineering (Draft)*. 2017.