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Application of MMS Data to Road Bridge Maintenance Management

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Abstract

In Japan, as many road structures age and labor shortages arising from a declining birthrate and aging population coincide with increasingly severe disasters, there is a growing need for efficient maintenance management. I-Construction 2.0 is progressing, and ICT construction and the 3D modeling of construction work using BIM/CIM which is Linking surveying design construction maintenance management with 3D data are underway. In addition, for the purpose of efficient road management, 3D data of expressways and national highways nationwide are being acquired and stored in MMS. Mobile Mapping System is a system that acquires 3D spatial information on the road and its surroundings while driving. However, despite this background, effective utilization of 3D data in maintenance management has not been well demonstrated. This study aimed to utilize 3D data for maintenance management by extracting deformations from two-period 3D datasets. Specifically, the deformations were quantified by difference analysis using the M3C2 algorithm. The utilization of 3D data in maintenance management is also discussed.

1. Introduction

1.1 Background

In Japan, many infrastructure structures were intensively developed during the period of high economic growth. As a result, aging structures have become a serious problem. In addition, climate change has led to an increase in damage from natural disasters such as floods and landslides caused by short duration heavy rains. Under these circumstances, it is becoming increasingly important to maintain and renew infrastructure to prevent disasters. As for road bridges, 55% of road bridges will be 50 years old by 2030, indicating that they are aging rapidly (Figure 1). Furthermore, the construction industry faces the challenges of a declining and aging workforce against the background of Japan's current demographic trends of low birthrate and aging population. As a result, it has become essential to improve the efficiency of maintenance and renewal work. [MLIT]

To deal with these issues, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has made the use of BIM/CIM (Building / Construction Information Modeling) in public works projects mandatory in principle starting from 2023. This policy is intended to promote and streamline the use of 3D models throughout the entire process of infrastructure projects, including surveying, design, construction, and maintenance. Among the technologies for acquiring 3D data, MMS (Mobile Mapping System), which can efficiently collect large-scale point cloud data from vehicles, is attracting attention. The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) began collecting 3D point cloud data using MMS from 2018, providing data to private companies and local governments to improve road management efficiency. Since then, MMS has been applied to many national roads and highway routes in Japan [MLIT].

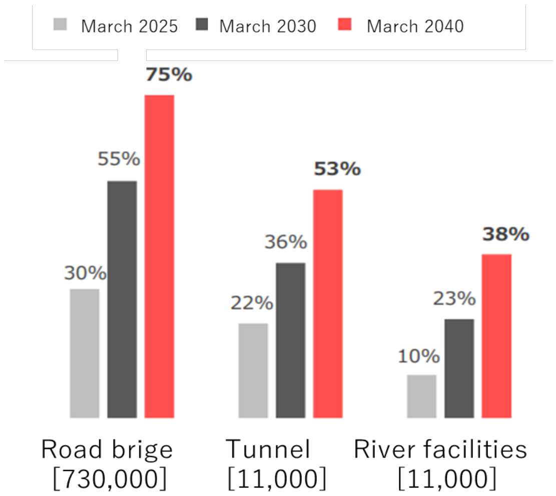

Figure 1. Percentage of structures that are 50 years old after construction Reproduced from MLIT, n.d.

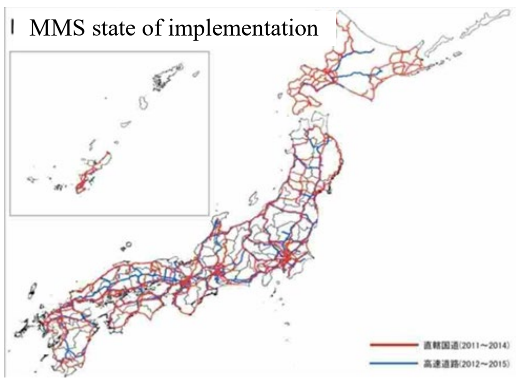

Figure 2. MMS data development status[MLIT] Reproduced from MLIT, n.d.

1.2 Road Bridge Inspection in Japan

This section provides an overview of road bridge inspection procedures in Japan and clarifies the policy of this study. The purpose of the road bridge inspection guideline is to prevent third-party damage to bridge users and the surrounding environment, to ensure the structural safety of bridges, and to support longevity and efficient maintenance and management. [MLIT] In principle, inspections are conducted once every five years by engineers with expertise, and the results are recorded and accumulated, mainly through close-up visual inspection, to observe long-term changes and evaluate structural integrity. However, the current inspection method relies on qualitative evaluation, and the result can vary among inspectors.

Damages to be inspected are broadly classified into steel elements and concrete elements. The main inspection items for steel members are cracks, looseness, collapse, fracture, and deformation, while for concrete members, cracks, loss and deformation, discoloration, and deflection are the main inspection items. In this study, we focus on "loss and deformation of members," which indicates superficial shape changes.

1.3 Purpose and Overview

This study aims to utilize 3D data in maintenance and management, and to examine methods of utilizing 3D data in bridges. Specifically, this study focuses on "member loss and deformation," which are superficial changes in road bridges, and attempts to quantify the extraction of deformations using 3D data. 3D point cloud data was acquired using a mobile laser scanning system (hereinafter called as MLS) and a Terrestrial Laser Scanner (hereinafter called as TLS), and data comparison, difference analysis, and quantification of the differences were conducted. Difference analysis and quantification of the differences using existing MMS data were also performed, and a discussion of effective utilization methods for maintenance and management was conducted.

2. Outline

2.1 Measurement Overview

Among several methods for acquiring 3D point cloud data, this study focuses on Simultaneous Localization and Mapping (SLAM). [Tomono, M] SLAM is a technology that simultaneously performs self-position estimation and map construction. In this paper, measurement devices using SLAM technology are referred to as MLS. in contrast to fixed laser scanning systems, MLS does not require installation of the device and point cloud data can be easily collected by carrying the device while walking. In this study, point cloud data was acquired using both MLS and TLS, and data obtained by each method were compared. The measurement place was the Ohi Bridge, located on National Route 2 in Okayama Prefecture (Figure 3). The bridge is extremely important for maintenance and management because of the extremely high traffic volume and the enormous impact it has on the surrounding environment. Four specimens and one verification point were placed on the north and west sides of the piers, respectively. On the north side, 50 cm square specimens of different thicknesses (10 mm, 30 mm, 50 mm, and 70 mm) were placed. On the west side, 30 cm square specimens of different thicknesses (thickness: 5 mm, 10 mm, 15 mm, 20 mm) were placed. Measurements were taken both before and after the installation of these objects; a difference analysis was performed by superimposing the point cloud data sets at the two time points.

Figure 3. Overall view of measurement location

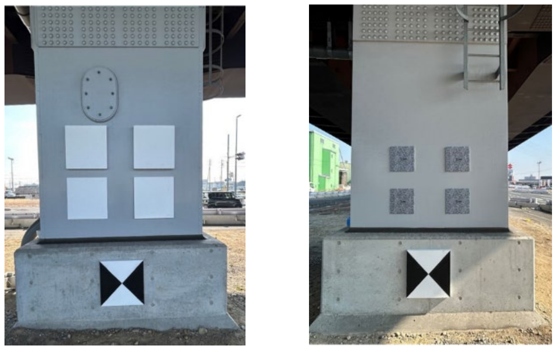

Figure 4. Installation of verification points(50cm × 50cm) and specimens (left : north side(50cm × 50cm), right : west side(30cm × 30cm))

Figure 5. Measurement (left: MLS, right: TLS)

2.2 Method of Analysis

In this study, all point cloud editing was done using [Cloud Compare], a free software. The Multiscale Model to Model Cloud Comparison (M3C2) algorithm, implemented in [Cloud Compare], was used for the difference analysis. M3C2 is an algorithm proposed by Lague et al. (2013) to directly and statistically evaluate 3D differences between point clouds. M3C2 statistically compares distance distributions along the normal direction at each reference point and calculates displacements and their confidence intervals. M3C2 is effective for complex terrain and structures and has superior noise tolerance and scalability. Many studies have utilized M3C2 in a wide range of fields, such as quantification of terrain evolution, infrastructure health assessment, and natural disaster risk monitoring. For details of the method, please refer to the literature [D. Lague].

Core points are extracted from the reference data of the two sets of data for difference analysis. Either all points are used as core points, or points extracted by sampling are used. Sampling is a method of setting a numerical value and sampling so that the minimum distance between point clouds becomes that value. This method is used when the number of target point clouds is large, and analysis takes time. At an arbitrary core point, points within a distance D/2 from point i in the surrounding point cloud (neighborhood point sequence) are extracted. For the extracted point group, find the optimal plane such that the sum of the root means square errors of the perpendicular distances between the points and the plane is minimized. The eigenvector obtained as the direction perpendicular to the optimal plane is the normal vector.

Project a cylinder of radius d/2 with core point i at its center, with its axis extending in the defined normal direction, and extract a group of points inside each of them. Extract two-point cloud data inside the cylinder and calculate the average value of each. The difference between the mean values is treated as the distance between the point clouds, and the same calculation is performed for all core points. The point cloud data with the data of the distance between point clouds is output as a result. Using the above method, a difference analysis of two-point cloud data is performed.

3. Verification of MLS and TLS

3.1 Measuring Equipment

The following is a description of the MLS and TLS used in this study. The MLS was a Libackpack DCG50H. [GreenValley International]. MLS can acquire up to 640,000 high-density point clouds per second while walking with the device on its back. It estimates its own position by accumulating relative movement information from LiDAR and IMU, but due to sensor noise and model errors, drift accumulates as the running distance and time increase. On the other hand, by using the GNSS mounted on this system as periodic correction information, the relative position estimation by SLAM is mapped to the absolute coordinate system, resulting in stable self-position estimation with greatly reduced accumulated errors in long-distance measurements. This enables point clouds to be acquired with absolute accuracy within ±5 cm. The main performance is shown in Table 1.

Next, the TLS employed in this research was a LeicaBLK360. [Leica Geosystems] This scanner incorporates a high-speed 360 000 point/second scan head in a compact housing with a weight of about 1.2 kg and a measurement range of up to 60 m and a distance accuracy of ±4 mm (at 10 m). The built-in dual-axis tilt adjustment mechanism enables acquisition of high-density point clouds in all 360° directions while automatically maintaining the horizontal position on a tripod. The main performance features are shown in Table 2.

Maximum Ranging Distance	120m
Relative error	≦3㎝
Absolute Accuracy	≦5㎝
Viewing Angle (FOV)	360° horizontal/90° ± vertical
Maximum movement speed	Approx. 20km/h
Internal Storage (TF Card)	512GB
Uptime	Approx. 2 hours
size	L1135×W318×H315㎜
weight	8.6kg
Number of LiDAR sensors installed	2 units
Scan Rate	640,000 points/s
Raging Accuracy	±1㎝
GNSS Systems	GPS/GLONASS/BeiDou
GNSS Positioning Accuracy	1㎝+1ppm

Table 1. .LiBackpack DCG50H performance

Imaging Scanner	3D scanner with spherical and thermal cameras
size	H165mm / Diameter 100mm
weight	1kg
capacity	Approx. 40 scans (typical)
Laser wavelength	830nm
Scan Scope	Horizontal 360° / Vertical 300°
Measuring range	Min 0.6m - Max 60m
Scanning speed	Up to 360,000 points/sec
Ranging accuracy	4㎜@10m/7㎜@20m
Built-in camera	1500-pixel three-camera system, 360° ×300°
Thermal Camera	Thermal image, 360° ×70°
Measurement speed	Approx. 3 minutes
Coordinate accuracy	6㎜@10m/8㎜@20m

Table 2. LeicaBLK360 performance

3.2 Verification of accuracy

The center of the verification point on the pier is acquired with a total station and its value is assumed to be the true value. The total station was Leica TS16[Leica Geosystems]. The height of the equipment is automatically measured and set at the push of a button. This feature reduces setting errors, eliminates the need for a tape measure, and ensures that you can always trust the height of your surveying instruments in use. It can measure with an accuracy of 1mm+1.5ppm~2mm+2ppm. Next, 3D point cloud data was acquired, and a point cloud close to the center point coordinates of the verification point was selected and its coordinates were acquired. The acquired points were compared with the true value, and the difference was evaluated as the accuracy. The results of the accuracy verification are shown in Table 3. When the TLS performance of 5 mm was used as the standard, there were cases in which the accuracy exceeded 5 mm. This may be because a different point was mistakenly selected when choosing the center coordinates of the point to be evaluated from the obtained 3D point cloud data. Next, regarding the MLS results, the following is discussed. In the case of the north side, a point cloud satisfying the machine performance requirement of 50 mm was obtained, but in the case of the west side, the result exceeded 50 mm. This may be due to the lack of overhead visibility when measuring the piers on the west side, which may have resulted in poor GNSS positioning accuracy. These results indicate the need to select measurement devices appropriate for the location, such as using non-GNSS instruments in areas without a clear view of the sky above the measurement point.

	North side		East side	
	TLS	MLS	TLS	MLS
ΔXY	9mm	15mm	2mm	67mm
ΔZ	20mm	16mm	10mm	22mm

Table 3. The result of verification of accuracy

3.3 Difference analysis

MLS and TLS measurements ware taken before and after the specimens of different thicknesses were installed on the piers. The point cloud before installation was defined as the first period, and the point cloud after installation was defined as the second period. A difference analysis was performed on the data obtained from the first and second periods. The ICP algorithm was used to overlay the two-point clouds before performing the difference analysis. Figure 6 and 7 show heat map diagrams of the point clouds where the difference analysis was performed. All the installed specimens were visually identifiable on the heat map.

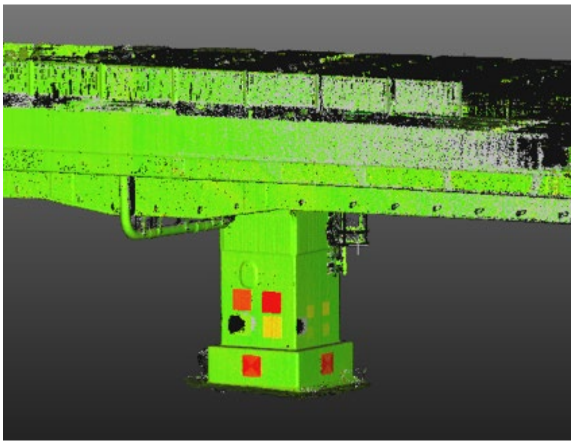

Figure 6. Deformation Extraction (TLS)

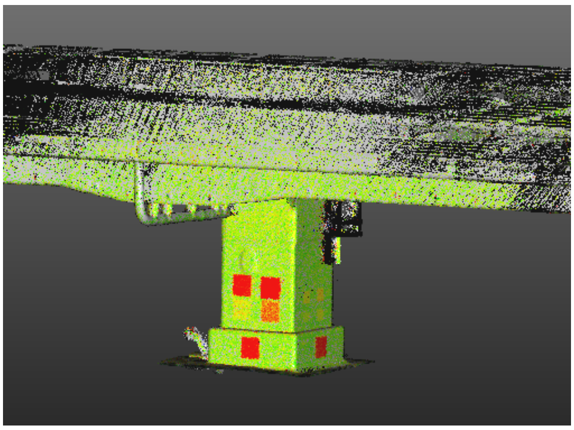

Figure 7. Deformation Extraction (MLS)

In addition, to quantify the differences corresponding to each specimen, the point cloud data of the specimens were extracted from the output results and their average values were calculated. For example, for a 5 mm specimen, the result is shown in Figure 8. This figure shows the bar graph of the results for each of the point clouds for which the difference analysis was performed. This method was performed on eight specimens, and the results were calculated as RMSE (root mean square error) values. The results are shown in Table 4: 4.84 mm for TLS and 1.65 mm for MLS. The RMSE values were also calculated for four data sets of 5 mm, 10 mm, 15 mm, and 20 mm located on the west side, and the results were 1.89 mm for TLS and 1.53 mm for MLS. These results indicate that changes of 5 mm or more can be identified by the heat-map diagram, and that changes of 5~20 mm can be quantified within an error of 2 mm. There was a case in which some TLS data was missing in this measurement (Figure 9.). This may have been due to the intensity of the reflected laser beam from the piers, which were at a distance of 10 m from the piers and almost directly perpendicular to them, causing the strong laser beam to return to the sensor. This could be the cause of the loss of data.

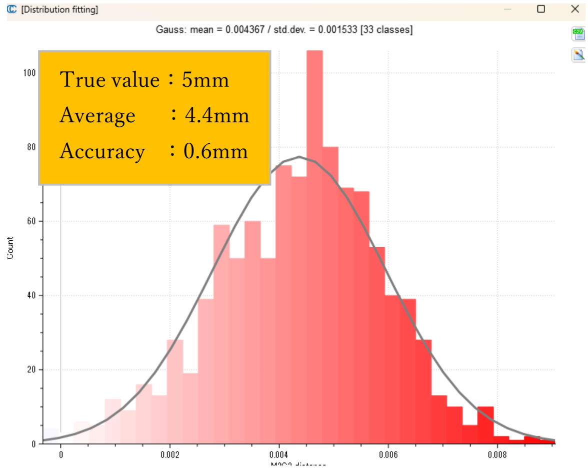

Figure 8. Example of quantification of difference analysis

	RMSE value	
	all data(8data)	5~20mm(4data)
TLS0、TLS1	4.85	1.89
MLS0、MLS1	1.65	1.53

Table 4. Results of quantification of difference analysis

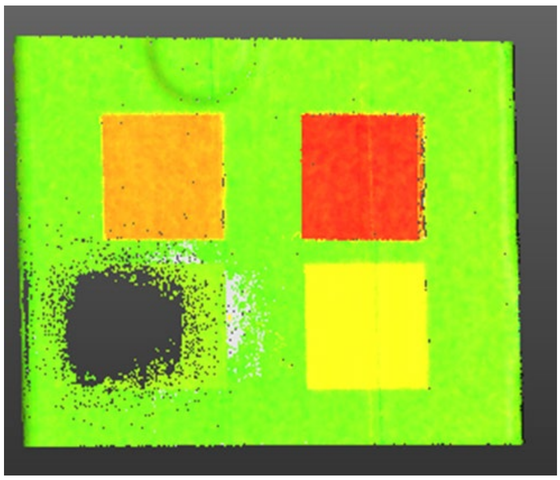

Figure 9. Case of missing data

4. Deformation extraction using different instruments

In this chapter, the same validation as in 3.3 is performed using MMS data. 3-D point cloud data acquired to create road ledger maps was used for the MMS data. MMS data was used for the first period and MLS and TLS with specimen installed were used for the second period. Two patterns of difference analysis (1: MMS, TLS 2: MMS, MLS) were conducted and compared each of them. Since the existing MMS point cloud included data from the upper parts of the piers, which sometimes caused issues with ICP alignment, only the relevant sections of the piers were extracted for alignment before performing the difference analysis. The results are shown in Figures 10 and 11. The area where the specimen was installed can be visually confirmed. As in 3.3, the location where the specimen was installed was cut out, and the RMSE value was calculated by finding the average of the differences. The results were 6.20 mm for MMS and MLS and 7.87 mm for MMS and TLS. In addition, four RMSE values of 5~20 mm were calculated, which were 7.71 mm and 7.95 mm. From the results, deformations larger than 5 mm can be seen in the heat map diagram, but the RMSE values are not quantified because they exceed 5 mm. This may be due to improper positioning by the ICP algorithm. When data from different measurement instruments are superimposed, significant misalignments can occur because of their respective systematic errors. The alignment is performed to suppress this displacement, but it was not performed properly. However, if one simply wanted to determine the deformation, a change of 5 mm or more could be confirmed.

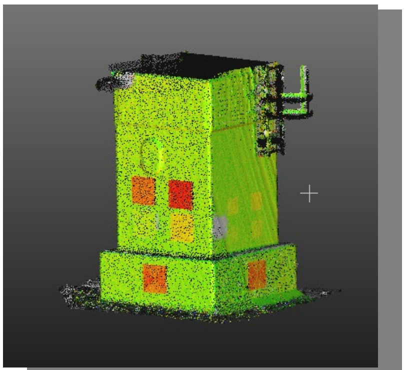

Figure 10. Deformation Extraction (MMS, TLS)

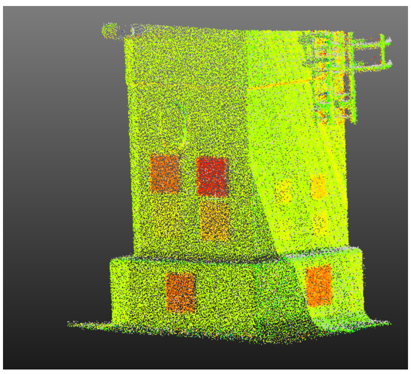

Figure 11. Deformation Extraction (MMS, MLS)

	RMSE value	
	all data(8data)	5~20mm(4data)
MMS0、TLS1	6.20	7.71
MMS0、MLS1	7.87	7.95

Table 5. Results of quantification of difference analysis using MMS data

5. Conclusion

The study aimed to quantify and improve the efficiency of road bridge maintenance and management through the use of 3D data. The findings obtained as a result of the validation are summarized as follows:

(1) By performing difference analysis using data acquired by MLS and TLS, respectively, changes of 5 mm or more could be identified in a heat map diagram, and deformations were extracted with accuracy within 2 mm for changes of 5~20 mm. The results suggest that this method can be utilized as a screening method for conventional inspections. And there was no significant difference between MLS and TLS: TLS measurements were made by setting up the machine four times on four sides of the pier and took about 30 minutes, while MLS measurements were completed in 20 minutes per measurement. The larger the area to be measured, the greater the difference in measurement time, so the use of MLS is expected to significantly reduce time and improve efficiency. However, the accuracy may be reduced when the overhead visibility is interrupted, so it is effective to use MLS in different ways.

(2) By utilizing existing MMS data, the presence or absence of deformities could be determined by checking heat-map diagrams, although accurate quantification could not be achieved. As for quantification, since the accuracy exceeded 6 mm in all cases, it is difficult to quantify the deformations at this time because the alignment may not have been done properly, and the overall alignment may have been wrong. Therefore, it is necessary to improve accuracy by processing the data through superimposition by ICP and filtering.

Utilization of 3D data for maintenance management will lead to more efficient and labor-saving inspections, as deformations can be identified simply by acquiring and analyzing 3D data, without the need for specialized knowledge. Based on the results, the tendency of “deformation and loss of members” of bridges can be identified and utilized as screening by accumulating the results in which deformations are confirmed and storing them for a long period of time. Issues to be addressed to utilize the system as an inspection aid include improving the accuracy of deformation quantification, establishing the effects of using different measuring instruments and how to deal with them, and defining the point cloud density required for differential analysis. Currently, the presence or absence of deformation of 5 mm or more can be identified, but quantification of the deformation results in an error of 5 mm or more. The accuracy of quantitative extraction needs to be improved for use as an inspection aid. In addition, both point cloud densities in this study were analyzed based on point clouds with more than 10,000 points per square meter. Verification of how small a change can be captured by how much density is needed. In this study, a 30 cm x 30 cm specimen was used as the deformation. Since such deformation does not exist in actual bridges, verification should be performed assuming actual deformation.

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