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Original article

Accuracy Analysis of Road Surveying and Construction Inspection of Underpass Section using Mobile Mapping System

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Abstract

MMS (Mobile Mapping System) is being used for HD (High Definition) map construction because it enables fast and accurate data construction, and it is receiving a lot of attention. However, research on the use of MMS in the construction field is insufficient. In this study, road surveying and inspection of construction structures were performed using MMS. Through data acquisition and processing using MMS, point cloud data for the study site was created, and the accuracy was evaluated by comparing with traditional surveying methods. The accuracy analysis results showed a maximum of 0.096m, 0.091m, and 0.093m in the X, Y, and H directions, respectively. Each RMSE was 0.012m, 0.015m, and 0.006m. These result satisfy the accuracy of topographic surveying in the general survey work regulation, indicating that construction surveying using MMS is possible. In addition, a 3D model was created using the design data for the underpass road, and the inspection was performed by comparing it with the MMS data. Through inspection results, deviations in construction can be visually confirmed for the entire underground roadway. The traditional method takes 6 hours for the 4.5km section of the target area, but MMS can significantly shorten the data acquisition time to 0.5 hours. Accurate 3D data is essential data as basic data for future smart construction. With MMS, you can increase the efficiency of construction sites with fast data collection and accuracy.

Keywords : Accuracy Analysis, Inspection, Mobile Mapping System, Road Surveying

1. Introduction

Various smart technologies such as smart construction, smart city, and self-driving cars are serviced based on spatial information, and are increasingly demanding the latest and accurate spatial information(Park and Lee, 2021; Park and Bae, 2020). However, since traditional surveying methods cannot cover the current needs, technologies for collecting spatial information using mobile objects such as drones and MMS are gradually spreading(Park and Um, 2019; Kim, 2020). Recently, data acquisition using drones or automobiles has been actively performed due to the improvement of accuracy and miniaturization of various types of sensors. In particular, in the case of a MMS for vehicles, it is receiving a lot of attention as it is used in the production of precision maps for autonomous vehicles and surveying of various road facilities, which are recently becoming an issue(Min *et al*., 2020; Park and Kim, 2019). MMS technology

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was first developed in 1991 and is currently entering the industrialization stage.Because the payload of the sensor for topography and landmark surveying is a vehicle, it is easy to access the area where changes have occurred, and it is highly accurate at the site in a short time(Liu *et al*., 2016; Tsai and Lin, 2017). It has the feature of acquiring 3D terrain data. MMS technology is being actively used as a new surveying technology for constructing geographic information centered on leading overseas surveying equipment manufacturers, but related research is still in its infancy in Korea. The domestic MMS application is centered around the field of map construction with precision. MMS applications in Korea are being used a lot in the map part with precision. The NGII (National Geographic Information Institute) produced a HD map for the West Coast Expressway between Seoul and Mokpo in 2018, and produced 4800 km of highways in 2019, and built a map with a precision of 5500 km by 2020.

In general, MMS acquires the location, attribute information, and image data of a feature using various sensors at the same time. Spatial information acquired using MMS can be usefully used for collecting information on terrain features that require high precision, such as roads and traffic facilities(Lee *et al*., 2020; Hong *et al*., 2017). Recently, precision map production using MMS sensors has been used in various fields such as surveying and managing road facilities, calculating earthwork volumes, and monitoring disasters. As a study case, a study on the use of MMS for maintenance of various road facilities was conducted(Lee *et al*., 2020). In addition, a study on the calculation of earthwork volume using MMS was carried out, and a study on 3D object recognition was carried out based on MMS(Hwang *et al*., 2018). However, most MMS studies conducted in Korea are studies on map and object extraction with precision, and there are insufficient cases applied to the construction field. Fig. 1 shows HD map built through MMS(www.ngii.go.kr).

In this study, road surveying was performed using MMS. In order to evaluate the possibility of using MMS, accuracy analysis was performed, and the applicability to inspection in the construction field using MMS was evaluated through comparison with the design values for the underpass section. Fig. 2 shows the study flow.

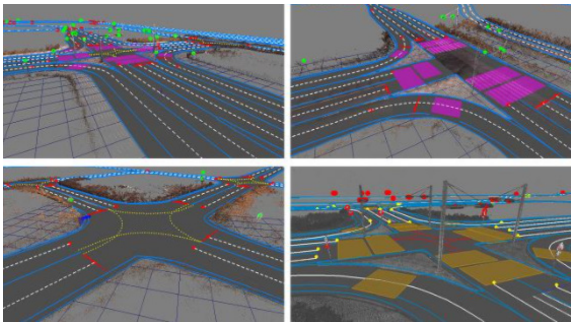

Fig. 1. HD Map Built Through MMS

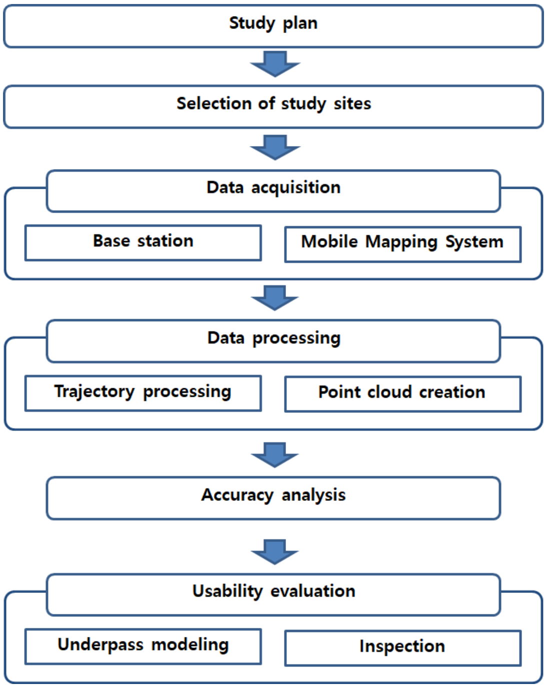

Fig. 2. Study Flow

2. MMS Technology

2.1 LiDAR

LiDAR (Light Detection And Ranging) surveying technology is a technology that measures information on the range and distance of an object by using the characteristics of light, and uses a laser pulse to determine the distance to the terrain and features. LiDAR surveying technology is a similar concept to radar technology, but it is a method of determining an accurate distance by scanning a laser pulse, not a radio wave, onto a terrain or a feature and measuring the time difference in which the reflected wave returns. LiDAR surveying is carried out by mounting laser scanners on various payloads such as ground, air, and satellite. Ground riders are used for investigation of rock slopes and structure restoration, aerial riders are used for mapping and urban planning, and satellite riders are used to explore the earth's crust, the height of land and glaciers, and vegetation. In addition, vehicle MMS is a surveying method that acquires three-dimensional topographic information such as precise map production for autonomous driving and river surveying by mounting sensors such as omnidirectional cameras, lidar, and encoders. The aviation and vehicle LiDAR system for obtaining 3D spatial information is a technology that calculates the 3D position of terrain and features by combining the position and attitude information determined by the laser scanner and GPS/INS system in general(Cho *et al*., 2021).

There are two methods of measuring distance using a laser, one using pulses and one using phase shift to observe the arrival time. In the method of using the phase difference, the distance is calculated by observing the difference between the emitted phase and the reflected phase using a CW (Continuous Wave) that is continuously emitted. Most of the LiDAR equipment currently in use uses the pulse method, and the general measurement principle of the pulse method is a method of multiplying the speed of light by observing the round trip time of the pulse. By using the time difference at which the pulse is emitted and received, the round trip time of the laser pulse is calculated as follows(Baek and Kim, 2021).

$$t_l = 2\frac{R}{C} \tag{1}$$

Where R is the distance between the laser scanner and the observation point, and c is the speed of light. At this time, the precision ΔR of the distance measurement is directly proportional to the precision ΔtL of the time measurement, which is expressed by follow Equation(Baek and Kim, 2021).

$$\Delta R = \frac{1}{2}c\Delta t_l \tag{2}$$

When a laser pulse is emitted to an object in a moving laser scanner, the scanning mirror with respect to the traveling direction emits the laser pulses to the left and right, which is orthogonal to the traveling direction, so that a signal that is elliptically spirally back-scattered can be obtained. After all, the meaning of scanning is to sample the surface of the object with high point density by refracting the laser for distance measurement according to a specific pattern.

2.2 IMU

The inertial navigation system mainly used to acquire the position and attitude value of MMS is a GPS/IMU-based inertial navigation system, and its performance is largely dependent on the accuracy of the IMU (Inertial Measurement Unit). The IMU consists of 3 gyro sensors and 3 acceleration sensors. The gyro that determines the accuracy of the inertial navigation system can be largely divided into a mechanical gyro, an optical gyro, and a micro gyro according to the operating principle. The mechanical gyro uses the inertia and precession of a rotating object, and these include FRIG (Floated Rate Integrating Gyro), ESG (Electrostatic Gyro), and DTG. Optical gyro uses the property of light during rotation called Sagnac Effect, and there are RLG and IFOG. Micro gyro is a miniaturized gyro to a size of several mm or less by using MEMS (Micro ElectroMechanical System) technology based on the recently developed semiconductor process technology, and uses the principle of Coriolis force proportional to the rotation of the vibrator. Until now, IMU-based INS with RLG or IFOG-based gyro sensor applied to MMS has been used, and INS applied with low-cost mass-produced MEMS-based IMU has been released(Ryu and Kim, 2014).

2.3 MMS

MMS is equipped with an image system, a laser scanner, a GNSS receiver, an inertial navigation system, a computer, etc. on a moving vehicle and integrates it to acquire information on terrain and features, and to construct high-quality spatial information data, navigation technology, photogrammetry, and image processing. It is a system that can measure various and complex terrain information in real time on the ground by adopting technology.

The concept of MMT (Mobile Mapping Technology) has changed according to the change of the underlying technology. Initially, it was used as a concept to measure the location and shape of a topographic feature using data collected through sensors(mainly aerial cameras) mounted on a moving object, and ground reference points measured separately. However, today, as the use of GPS and Inertial Navigation System is common and integrated technology is developed, 3D position measurement is performed only with data collected using a sensor mounted on a moving object without using a separate ground reference point. It is used as a concept of a technology that can be performed(Park and Um, 2017).

3. Data Acquisition and Trajectory Processing

In this study, a road section located in Seoul was selected as the study destination for road surveying and inspection using MMS. The study site is an area that needs to be surveyed as a road improvement project is planned. It is an area that takes a lot of time and manpower for detailed surveying of roads and surroundings with traditional surveying methods. Fig. 3 shows the study area.

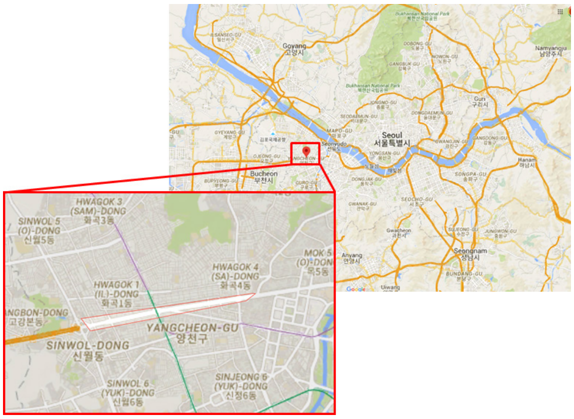

Fig. 3. Study Area

The MMS used for data acquisition is Trimble's MX9. Fig. 4 shows the MX9 and its main specifications(www.trimble.com). MX9 is equipped with two 3D laser scanners based on GNSS/IMU, and six cameras.

Item	Definition
Operating temperature	0˚C ~40˚C
Power	DC 24V
IP	IP64
Weight	37kg (roof rack : 18kg)
Operating Interface	Tablet or Notebook WiFi or LAN cable
Scan FOV	360˚ full circle
Scan Speed	2,000,000 point/sec (Dual Laser)
Maximum Scan Speed	500 line/sec (20 ~ 500 scan/sec)
Laser Pulse	300kHz ~ 1MHz
Distance	420m @ 600 KHz (natural target >80%)
Accuracy	5mm
Precision	3mm

Fig. 4. MX9 and Specification

Data was acquired for the 4.5km section of the road in the study site. To improve accuracy, a GNSS base station was installed and data was logged at 1 second intervals. Data was acquired by round trip of the road section, and the time required to acquire the data was a total of 30 minutes. Trajectory processing processed MMS data based on the GNSS data of the base station. The software used is Applanix's POSPac software. The flow for MMS data processing is shown in Fig. 5.

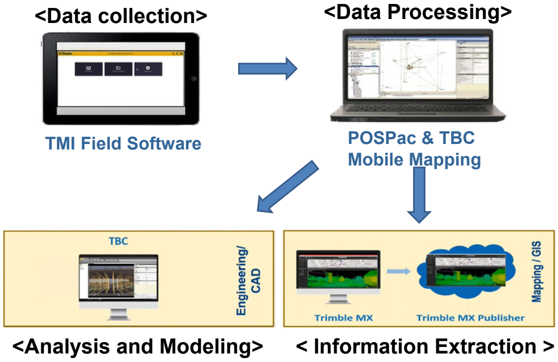

Fig. 5. MMS Data Processing Flow

Trajectory processing was performed for the entire section, and was processed based on GNSS base station data. Trajectory is the basic data for creating a point cloud, and 200hz point data for the vehicle's movement path is created. fig. 6 is the trajectory processing screen, fig. 7 shows the position RMSE for the trajectory processing result.

As shown in Fig. 7, trajectory processing result showed RMSE within 0.04m in most of the sections, and a high RMSE of 0.4m in the underpass section. This is because the GNSS signal cannot be received. Indicator data was used.

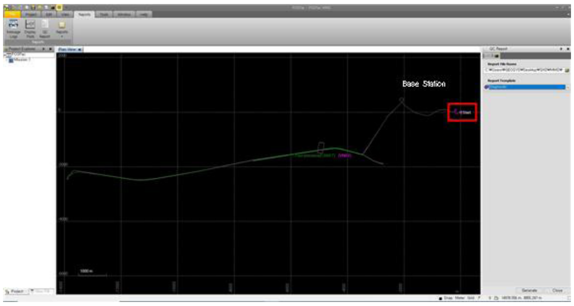

Fig. 6. Trajectory Processing Screen

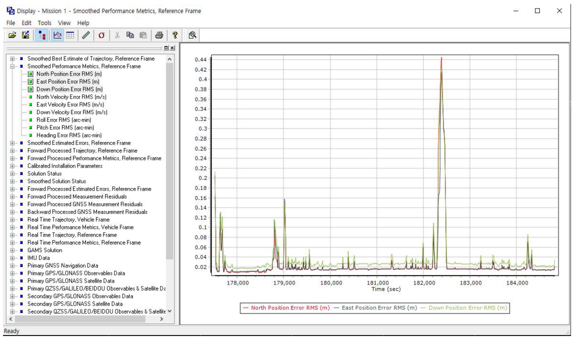

Fig. 7. Position RMSE for the Trajectory Processing Result

4. Point Cloud Creation and Data Utilization

point cloud was created by processing laser scanner data using the trajectory processing result. The software used for data processing is TBC (Trimble Business Center), and the point cloud was created for a range of 100m around the vehicle. Fig. 8 shows the point cloud creation section. Since data was acquired by dividing the entire section into several for data processing, each data is classified by color as shown in the figure. Fig. 9 shows a part of the created point cloud.

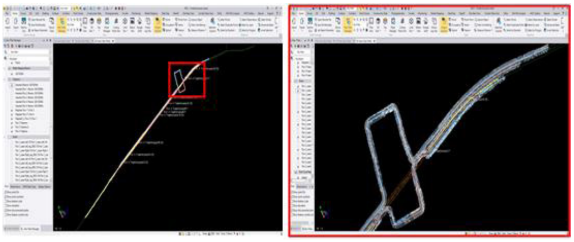

Fig. 8. Point Cloud Creation Section

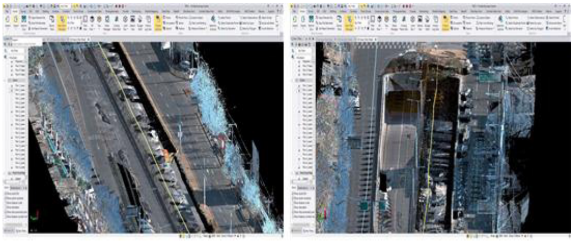

Fig. 9. Part of the Created Point Cloud

In order to verify the utility of the generated point cloud data, an accuracy analysis was performed on the checkpoint. A total of 10 checkpoints were used, and road markings were used. Acquisition of coordinates for road markings was performed by the VRS (Virtual Reference Station) method using GNSS. Table 1 shows the coordinates of the checkpoints, and Fig. 10 shows some of the checkpoints used in the accuracy analysis.

Table 1. Coordinates of the checkpoints

Check Point	X(m)	Y(m)	H(m)
1	547337.976	185337.508	16.726
2	547355.212	185424.968	15.555
3	547398.897	185643.150	13.102
4	547465.905	185945.481	9.629
5	547492.122	186075.553	9.617
6	547554.863	186338.892	9.647
7	547598.909	186558.876	4.926
8	547628.551	186718.012	4.727
9	547729.326	187361.191	8.586
10	547806.847	187920.190	2.547

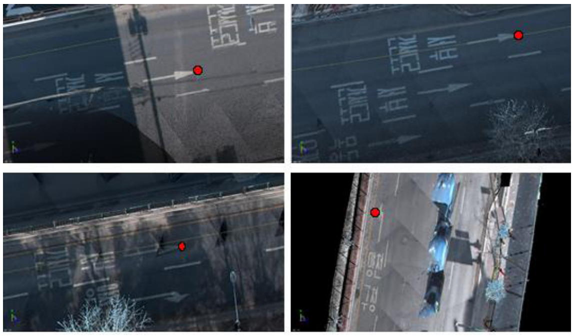

Fig. 10. Checkpoints

The accuracy analysis compared the VRS performance and the coordinates extracted from the point cloud made with MMS. The coordinates were extracted by selecting the nearest point among the point cloud of the road sign. Table. 2 shows the results of the accuracy analysis.

Table 2. Results of the Accuracy Analysis

Check Point	dX(m)	dY(m)	dH(m)
1	0.081	0.061	0.093
2	0.093	0.055	0.082
3	0.082	0.062	0.083
4	0.081	0.064	0.083
5	0.093	0.061	0.093
6	0.092	0.072	0.082
7	0.096	0.081	0.071
8	0.081	0.091	0.083
9	0.077	0.077	0.092
10	0.055	0.081	0.084
Maximum deviation(m)	0.096	0.091	0.093
RMSE(m)	0.012	0.015	0.006

As shown in Table 2, the accuracy analysis results showed a maximum of 0.096m, 0.091m, and 0.093m in the X, Y, and H directions, respectively. Each RMSE was 0.012m, 0.015m, and 0.006m. These result satisfy the accuracy of topographic surveying in the general survey work regulation, indicating that construction surveying using MMS is possible. Table. 3 shows allowable accuracy in general survey work regulation(http://www.law.go.kr).

Table 3. Allowable Accuracy in 1:1,000 Digital Topographic Map Production

Item	Horizontal	Height
Allowable Accuracy (Maximum Deviation)	0.40m	0.30m

As shown in the accuracy analysis result, these maximum deviation and RMSE values indicate that road surveying using MMS is possible. Road surveying using MMS is expected to greatly improve the efficiency of road surveying because it enables fast data acquisition. In addition, it is considered to be suitable for large-scale surveying because it can reduce the number of manpower used for work. Table 4 shows the results of comparison between traditional surveying methods using GNSS and MMS. In order to compare the MMS and the working time, two people used the GNSS and the total station to compare the length of time surveying the section at intervals of 20m. Based on the survey for the 4.5km section, the input manpower is the same, but MMS can greatly shorten the working time.

Table 4. Comparison Between Traditional Surveying Methods using GNSS and MMS

Item	Number of Manpower	Time
GNSS	2	6 hour
MMS	2	0.5 hour

In this study, a 3D model was created using the design data of the underpass section in order to understand the utility of MMS in the construction field. Inspection of the point cloud data generated through the 3D model and MMS was performed. The design data consists of the longitudinal line of the underpass section and the standard section of the underpass section. To generate 3D design data, a standard section was placed on the longitudinal line of the road, and a mesh was created along the longitudinal line. Fig. 11 shows the longitudinal line and the standard section of the underpass. Fig. 12 shows the creation of a 3D model using design data.

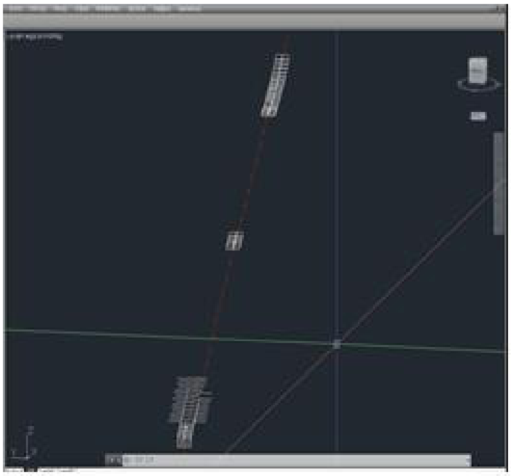

Fig. 11. Longitudinal Line and Standard Section

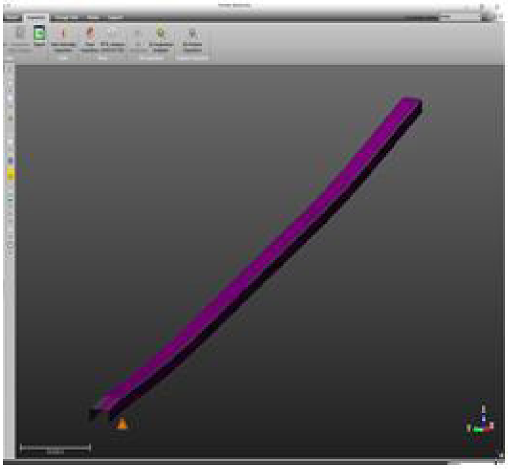

Fig. 12. 3D Model using Design Data

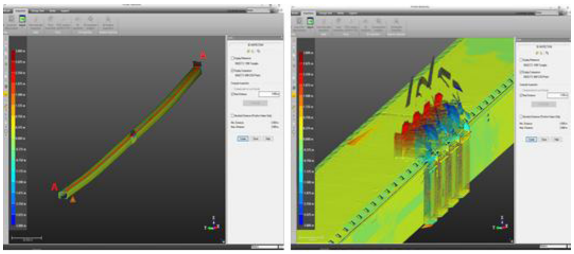

Fig. 13. Inspection of the Underpass

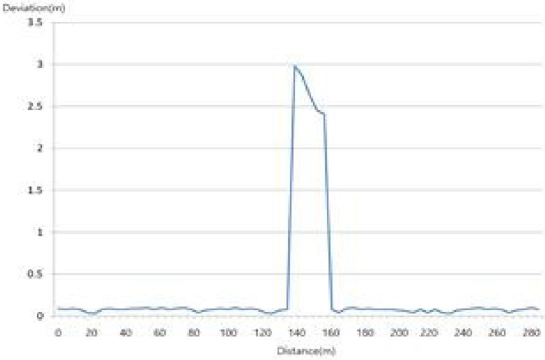

Fig. 14. Inspection Result of A-A Section

Figs. 13 and 14 shows the inspection results for the underpass. As shown in the figure, deviations in construction can be visually confirmed for the entire underground roadway. Overall, the deviation for construction was within 0.10m, but there was a large deviation value in some areas. This part is considered to be different from the original design drawing because the additional structure was installed after the underpass construction. Road surveying and inspection of structures using MMS can significantly improve work efficiency because faster data acquisition is possible compared to traditional surveying methods. Through additional research, it is necessary to present the results of the quantity calculation for construction work or the inspection of the structure. For inspection with design values in construction work, it is necessary to periodically perform construction surveys and compare the results. Until now, GNSS has been mainly used for construction surveying, but this does not fully reflect the shape of the actual building, and there is a disadvantage that it takes a lot of manpower and time for the survey. The model of the target area using 3D design and the construction survey method using a MMS can be a method that can solve the shortcomings of the existing method. And such accurate 3D data is essential data as basic data for smart construction.

5. Conclusions

In this study, road surveying and inspection of construction structures were performed using MMS. The target site for the road improvement project was selected, data was acquired using MMS, trajectory processing was performed, and a point cloud was created. Data acquisition using MMS was able to significantly shorten the data acquisition time compared to the traditional GNSS method. The traditional method takes 6 hours for the 4.5km section of the target area, but MMS can significantly shorten the data acquisition time to 0.5 hours. In order to suggest the possibility of using road surveying using MMS, the accuracy was evaluated by comparing it with the VRS survey results. The accuracy analysis results showed a maximum of 0.096m, 0.091m, and 0.093m in the X, Y, and H directions, respectively. Each RMSE was 0.012m, 0.015m, and 0.006m. These result satisfy the accuracy of topographic surveying in the general survey work regulation, indicating that construction surveying using MMS is possible. In addition, a 3D model was created using the design data for the underpass road, and the inspection was performed by comparing it with the MMS data. Through inspection results, deviations in construction can be visually confirmed for the entire underground roadway. The model of the target area using 3D design and the construction survey method using a MMS can be a method that can solve the shortcomings of the existing method. And such accurate 3D data is essential data as basic data for smart construction. The use of MMS can improve work efficiency in the construction field with fast data acquisition and accuracy.

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