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AN OBSERVATIONAL STUDY ON THE MEASUREMENT OF STREET TREES USING A MOBILE MAPPING SYSTEM TO OBTAIN 360-DEGREE IMAGES

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Abstract A method to evaluate street trees using a Mobile Mapping System (MMS) to obtain 360-degree images to analyze three-dimensional position data was examined. Measuring tree heights and diameters at breast height (DBHs) using MMS were examined and compared with field survey data using a laser rangefinder and a caliper gauge. As a result, the average of the root-mean-square error (RMSE) of tree height and DBH were 1.07 m and 3.3 cm, respectively. Although the MMS is not equipped with a laser scanner, the RMSE of DBH was comparable with previous studies. The heights were underestimated where tree canopies covered the sky, which resulted in a large RMSE of the height. For DBH, the difference in measurements between methods was small, averaging about 3 cm.

Keywords: Mobile Mapping System (MMS), tree height, diameter at breast height (DBH)

1. Introduction

The evaluation of the state of greens in urban areas is an important issue. Urban greens bring benefits including reducing air pollution, mitigating the heat island effect, and promoting mental and physical health (Zoulia *et al*. 2009; Haq 2011; World Health Organization 2016). In Tokyo, Japan, municipalities survey the condition of the greens once every five years. When investigating a wide area of cities, manual field surveys are time-consuming and costly, so aerial photography and satellite remote sensing are used together. In recent years, aerial photographs are often taken as digital multiband data with high spatial resolutions of about 10 cm (Hara *et al*. 2015). Also, the use of UAVs (Unmanned Aerial Vehicles) as a new remote sensing platform, has been growing. UAVs can take images from low altitudes and from lateral directions, which can complement blind spots in the photography of crewed aircraft. However, obtaining information on a single tree, such as tree height and DBH (Diameter at Breast Height), using aerial photography is not simple. Additionally, the flight of UAVs in an urban area is severely restricted by laws in Japan from the viewpoint of safety.

To address these factors, using a Mobile Mapping System (MMS) to capture green efficiently from the ground has been utilized. MMS is a system that can obtain various types of geospatial information with sensors mounted on a vehicle. Although the target is restricted to roadside greens using MMS, it has the potential to measure trees in a wide area efficiently. For example, Jaakkola *et al*. (2010) measured trees within about 20 m horizontal distance from the MMS. Holopainen *et al*. (2011) measured trees within about 15 m by the MMS. In these studies, the accuracy rate for extracting trees from the point cloud data was about 90% (Jaakkola *et al*. 2010; Weinmann *et al*. 2017). The measurement accuracy of DBH was 2.8 cm in Holopainen et al. (2011), with an error of 10%. In Čerňava et al. (2017), the accuracy of DBH was 2.65 cm for trees with DBH of about 9–85 cm.

In previous studies, the measurement of trees by MMS was studied mostly using MMS equipped with laser scanners. Alternatively, another approach using wide-angle cameras and photogrammetric methods instead of laser scanners, is available to estimate three-dimensional (3D) position information. There are several advantages in this method. It is less expensive and does not require the processing of large numbers of laser point clouds. In addition, it is easy to understand objects visually because we can measure objects while viewing the image. In forested areas, fisheye cameras with a 180-degree angle of view have been used to evaluate greens for estimating leaf density of trees (LAI, Leaf Area Index; Hasegawa *et al*. 2013). However, no study has examined the measurement of street trees using MMS by image analysis of wide-angle cameras.

Another reason why we should consider the use of wide-angle cameras is that they have become widely recognized in recent years. For example, Google Street View is able to examine the world with omnidirectional images captured by cameras on vehicles (https://www.google.com/streetview). Also, such photographs are often taken by the general public. Many panoramic photographs taken with action cameras and smartphones are posted on SNS (Luchev *et al*. 2017).

As such, in this study, we examined the method of capturing street trees using MMS, which obtains 360-degree images to develop an inexpensive and simple system in the future. Specifically, we tried to measure heights and DBHs of single trees using MMS which were compared with field survey results for the reference data.

2. Methods

Suginami Ward, Tokyo, Japan, was selected as the study area (Fig. 1) because it has many street trees, including large-scale zelkova trees. Four street sections with an extension of 100 m in the area (A - D in Fig. 1) were selected. Sections A and B, Nakasugi-dori, are characterized by zelkova trees with canopies covering the sky. At the time of the survey, Section A was pruned, while Section B was not pruned. Section C, the street in front of Koenji railway station, is about the same width as Nakasugi-dori, but the street trees are a variety of short height species. Section D, Itsukaichi-kaido, extends east and west with street trees of *Acer buergerianum*.

This study used an MMS named “IP-S2 Lite”, made by TOPCON CORPORATION (Fig. 2). The system consists of the main unit mounted on a vehicle roof, a power supply in the vehicle, and a control computer. The main unit has a CCD (Charge-Coupled Device image sensor) camera equipped with six lenses, a GNSS (Global Navigation Satellite System) antenna (supports GPS and GLONASS), and an IMU (Inertial Measurement Unit). The main unit is connected to a lead-acid battery and a computer in the vehicle. The computer controls the capture of the image and stores the images and position information. The camera takes 16 shots of 360-degree photographs per second of about 4 million pixels (1,400 x 2,800 pixels) while driving. If images are taken while driving at 40 to 50 km/h, the amount of data stored will be about 20 to 30 gigabytes per kilometer.

The data was obtained using the MMS while driving on December 20, 2013. The 3D position information was estimated from the obtained image by extracting and calculating feature points (camera vectors) in the image. 3D camera positions and attitudes were determined by tracking the movements of multiple points in every frame to calculate the camera vectors (TOPCON

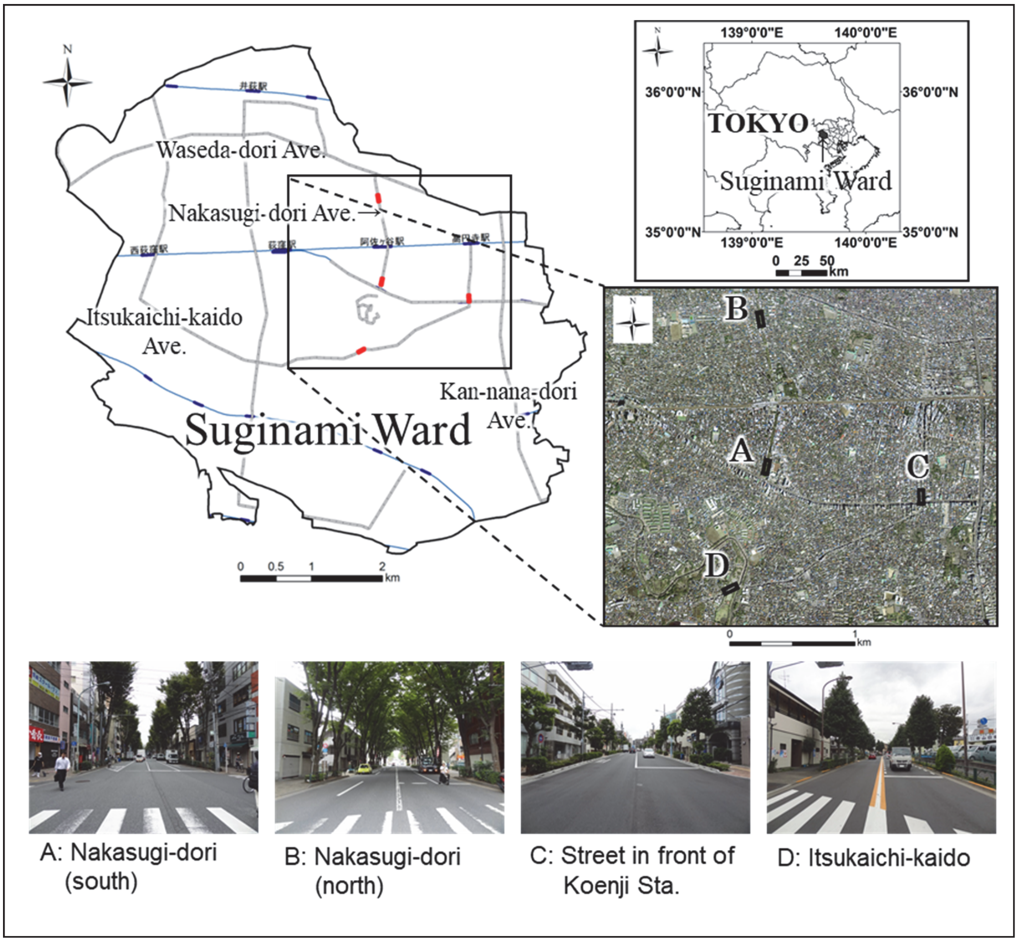

Fig. 1 Study area.

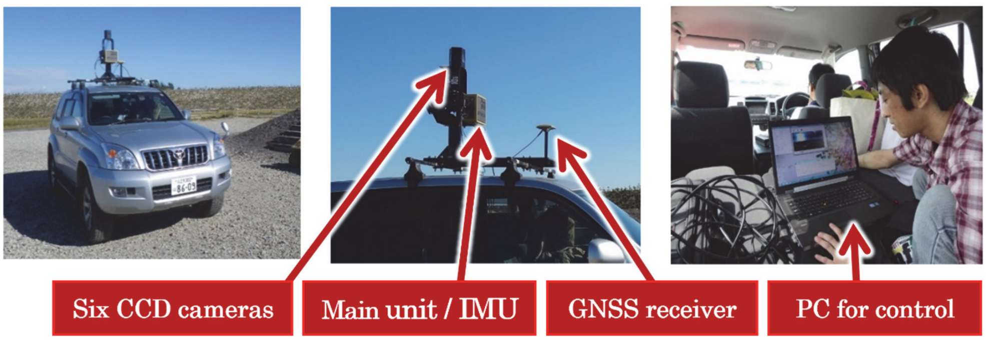

Fig. 2 Overview of the MMS used in this study.

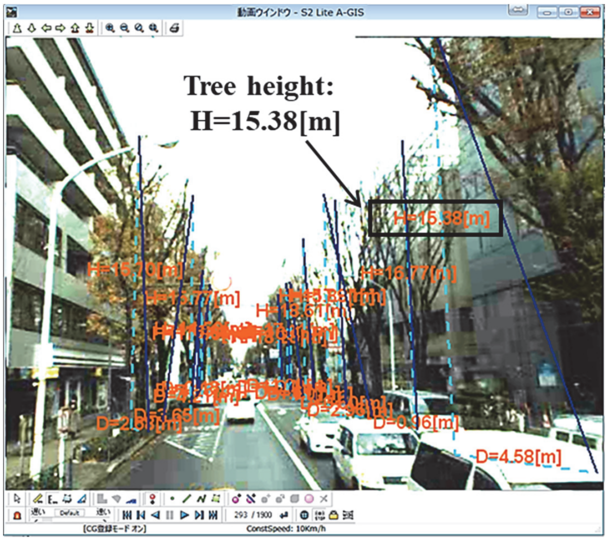

Fig. 3 Example of the screen on the measurement by the MMS.

CORPORATION, 2014). After the process, we measured tree heights and DBHs from the data. An example of the measurement screen is shown in Fig. 3. The calculated distance is displayed on the screen when two points are located in the image. For tree height, the vertical heights between the top and the bottom of each tree were measured. For DBH, the horizontal distances between both ends of the trunk of each tree at the height of 1.3 m from the ground were measured. 107 trees of four sections in total were measured.

Tree heights and DBHs of the same trees as the reference data were measured with a portable laser rangefinder (TruPulse 360, made by Laser Technology Inc.) and a caliper gauge, respectively, on January 31, 2014. The reference data and the measurements by the MMS were compared by calculating root-mean-square error (RMSE).

3. Results and discussion

The results of the measurements are shown in Table 1 and Fig. 4. At the mean value of all trees, the difference (MMS - laser rangefinder) for tree height was -0.042 m, that is, the measurement of

Table 1 Overall results of tree measurements (m).

	Tree height	DBH
Mean (laser rangefinder and caliper gauge)	11.269	0.319
Mean (MMS)	11.227	0.322
Difference	-0.042	0.003
RMSE	1.067	0.033

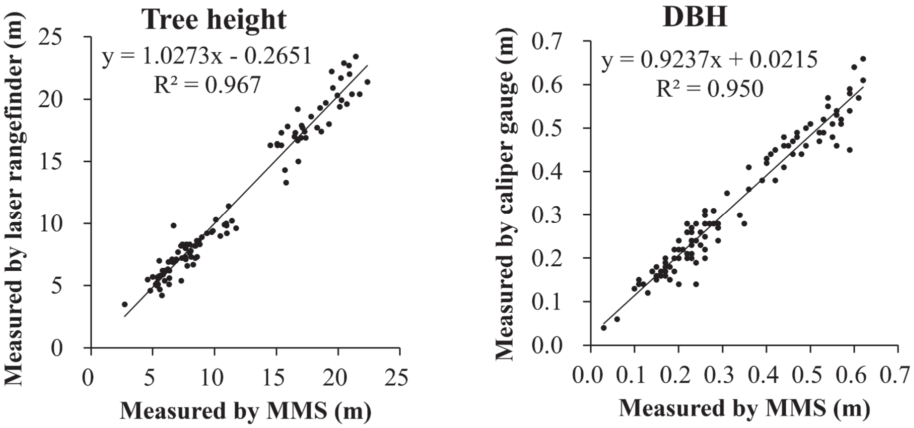

Fig. 4 Scatter diagrams of measurements of tree height (left) and DBH (right).

MMS was the underestimation of approximately 4 cm. The RMSE of tree height was 1.07 m. For DBH, the difference was +0.003 m, that is, overestimation of 3 mm. The RMSE of DBH was 0.033 m.

In previous studies, RMSEs of DBH were approximately 2.7 cm (Čerňava *et al*. 2017) to 2.8 cm (Holopainen *et al*. 2011) and were measured by MMS equipped with a laser scanner. Therefore, the measurement of this study, 3.3 cm for the RMSE of DBH, has a comparable accuracy, considering the MMS was not equipped with a laser scanner. Besides, the accuracy of tree height was not conducted in the previous studies. Considering that the laser rangefinder has an accuracy of ±30 cm for the distance and ±0.25 degrees for the inclination (Laser Technology Inc. 2017), the method of this study can measure tree height and DBH with practical accuracy.

The average values of tree height, DBH, differences between two measures, and the RMSE for each section, are shown in Table 2. Regarding tree height, the RMSE on Section B was the largest. Since the canopies mostly covered the sky in Section B (Fig. 1, Fig. 5 (a)), obtaining pictures of the treetops from the position of the roadway where the MMS obtained the data was difficult. The second-largest RMSE was Section A. Trees of this section also had a relatively large canopy, but

Table 2 Measurements of each section (m).

Section	*n*	Tree height				DBH			
		Mean (laser rangefinder)	Mean (MMS)	Difference	RMSE	Mean (caliper gauge)	Mean (MMS)	Difference	RMSE
A	19	15.65	15.48	-0.17	1.27	0.470	0.481	0.011	0.041
B	28	17.20	16.99	-0.21	1.36	0.422	0.427	0.005	0.032
C	27	5.88	5.83	-0.05	0.48	0.234	0.244	0.010	0.035
D	33	8.08	8.36	0.28	0.85	0.202	0.188	-0.013	0.029
All trees	107	11.27	11.23	-0.04	1.07	0.319	0.322	0.003	0.033

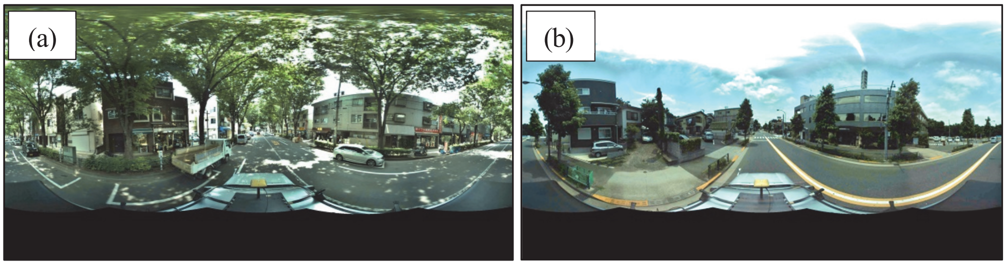

Fig. 5 Examples of 360-degree images at the site with large canopies (a) and small canopies (b).

because of pruning, the difference was smaller than in Section B.

While the RMSE of Sections C and D were small, the trees in these sections were relatively short, and the canopy was small (Fig. 1, Fig. 5 (b)). This was probably due to the fact that the elevation angle for measurement was smaller for both the laser rangefinder and the 360-degree image. That is, the changes in tangent were small at small elevation angles, resulting in a small error in height. However, regarding Section D, the tree height by the MMS was an overestimation of 28 cm. A possible reason for this is that the treetops in the section were thin and difficult to find with the laser rangefinder. For this reason, we measured slightly below the tops at the field survey. This problem does not occur with the MMS measurement because we could point to the treetops in the image. The height of the camera is also the reason for the difference. The camera of the MMS was mounted on the roof carrier of the vehicle, approximately 2.5 m above the ground. It was much higher than the eye level of the field survey, making it easier to find the treetops.

On DBHs, the difference by section was not as large as the tree height. As with tree height, the mean values were larger in Sections A and B, and smaller in C and D. Though, the RMSE of each section was about 3–4 cm, and the maximum difference between the means of the methods was only about 1.3 cm. This result indicates the measured values of DBH do not vary much depending on the method.

The measurements classified by size are shown in Table 3. The results show that the error tends to increase as the height increases. A possible explanation is that with the greater height, the greater the error of each method because it became more difficult to capture the treetop. The tendency was remarkable in this study because tall trees had large canopies in the study area. Also, the differences between the means showed that the greater the height, the greater the tendency to underestimate. As described above, capturing the treetops with large canopies was difficult and the lower portions were measured rather than the treetops. Whereas DBHs did not show any tendency of underestimation / overestimation or difference in RMSE by size. Like the comparison for each section, DBHs had seemingly less difference in the measured values depending on the method.

5. Conclusion

The results of this study suggest that the MMS, which obtains and analyzes the 360-degree image, is possible for measuring trees, for example, tree heights and DBH of street trees. The accuracy of measurements was practical compared with the results by the field survey and by the MMS which is equipped with a laser scanner. However, it was not easy to measure the trees which

Table 3 Measurements classified by size (m).

		n	Mean (laser rangefinder and caliper gauge)	Mean (MMS)	Difference	RMSE
Tree height	Less than 10m	65	7.02	7.16	0.14	0.864
	10-20m	31	16.50	16.38	-0.12	1.187
	20m and over	11	21.66	20.72	-0.94	1.637
	All trees	107	11.27	11.23	-0.04	1.067
DBH	Less than 20cm	25	0.151	0.151	0.000	0.032
	20-40cm	45	0.258	0.255	-0.003	0.031
	40cm and over	37	0.501	0.513	0.012	0.037
	All trees	107	0.319	0.322	0.003	0.033

have large canopies.

To develop cheaper and simpler systems in the future, further studies will be required in terms of data acquisition and the construction of 3D information. For the acquisition, a more quantitative analysis is needed for the trend that the error increased with the canopy size shown in this study. In other words, it is necessary to clarify the relationship between the error and the crown size or the sky factor and to clarify the range in which the accuracy can be ensured. When the crown size exceeds a certain threshold, some different approaches, such as a combination with UAVs, should be utilized. Also, understanding the characteristics of the lens is necessary. For low-cost cameras, verification and correction are important because the lens distortions can be large. For the construction of 3D information, utilizing open-source techniques such as SfM (Structure from Motion; Westoby *et al*. 2012) could be practical.

Furthermore, when updating data in the future, it can be expected that data will be obtained and used by citizens. Urban greens are currently recognized as an important asset of the community, and conservation movements by citizens are actively conducted (Lepczyk *et al*. 2017). If greens can be evaluated by analyzing photographs accumulated as a database on SNS in the future, the real situation of urban greens will be evaluated more widely and densely.

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