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Application of 3D Laser Scanning Data for Forest Survey and Timber Volume Estimation

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Recently, the development of geospatial information acquisition technology has been accelerating. Interest in this technology as a way to solve the problem of labor shortages in the forest sector is increasing. In this study, a forest survey was conducted by acquiring data on trees using a laser scanner and detecting individual trees through processing and analysis. Data on the study site were acquired using terrestrial and drone-mounted laser scanners, and a georeferencing point cloud was effectively created through data processing. Diameter at breast height, tree height, crown, and crown-based height were effectively measured by removing the ground from the point cloud data generated in the forest area and classifying individual trees. In addition, we suggest that water pipe measurement is possible through the combination of drone-mounted laser scanner and terrestrial laser scanner data. The existing volume calculation method using a timber volume table and the method using a point cloud were compared. For this comparison, we propose a method of calculating the timber volume using the point cloud.

1. Introduction

Most of Korea's land area is forested, and its proportion of forested area is more than twice the global average and is the fourth highest among the Organization for Economic Co-operation and Development (OECD) countries.(1) Forests in Korea provide an economic and public value of 174 trillion won annually to the public, and effort is needed to preserve and manage these forests.(2,3) Korea's official forest resources survey started with the first national forest survey in 1972–1976, which was followed by the second (1978–1980), third (1986–1992), fourth (1996–2005), and fifth (2006–2010) national forest surveys. The sixth national forest survey has been under way since 2011,(4–6) in which changes in forest resources and ecosystems over time are being monitored to understand the health of forest ecosystems at fixed sample points considered in the fifth survey.(7,8)

Recently, various international agreements and organizations, such as the Convention on Climate Change, Sustainable Forest Management, and Food and Agriculture Organization

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(FAO), have mandated the submission of various national forest resource statistics on not only forest resources but also the overall forest environment, such as the forest location and ecology. The fifth national survey was conducted after the reorganization of needs for these statistics into a system, and various and useful information obtained through the forest resources survey will be provided for analysis and to meet the demand for various forest statistics in Korea and abroad.(9–12)

Along with the development of the fourth Industrial Revolution and IT, spatial information acquisition technology is rapidly developing.(13,14) In the existing forest survey, the measurements of the number of tree objects, height, diameter at breast height (DBH), and so forth are being performed by manual methods, but the use of laser scanners enables faster surveys than conventional methods.(15) However, in previous studies, only the DBH and tree height were measured. In addition, the timber volume was calculated using a timber volume table. Table 1 shows an example of a timber volume table.(16)

In this study, forest data are acquired using terrestrial and drone-mounted laser scanners, and through processing and analysis, the DBH, tree height, crown, crown-based height, and timber volume are calculated to perform a forest survey. Figure 1 shows the flow of the study.

2. Materials and Methods

A 3D laser scanner operates on the same principle as a total station. A total station is used to direct a laser beam at a specific point to be measured and to measure that point. On the other hand, since a 3D laser scanner has a measurement speed of millions of points per second, it can measure the 3D coordinates of an object in a short time. Figure 2 shows the data acquired by a 3D laser scanner.

A 3D laser scanner calculates the distance by measuring the time it takes for the laser to be reflected and return. In this study, a time-of-flight (TOF)-type scanner was used. The formula for calculating the distance in the TOF method is(17)

Table 1
Example of timber volume table.

DBH / Height	6	8	10	12	14	16	18	20	22	24	26	28
5	0.0080	0.0135	0.0202	0.0281	0.0372	0.0475	0.0590	0.0716	0.0854	0.1003	0.1164	0.1337
6	0.0096	0.0162	0.0243	0.0338	0.0448	0.0572	0.0710	0.0862	0.1028	0.1207	0.1400	0.1608
7	0.0113	0.0190	0.0284	0.0396	0.0524	0.0669	0.0830	0.1008	0.1202	0.1411	0.1637	0.1880
8	0.0129	0.0217	0.0325	0.0453	0.0600	0.0766	0.0951	0.1154	0.1376	0.1616	0.1875	0.2152
9	0.0145	0.0245	0.0366	0.0511	0.0676	0.0863	0.1071	0.1300	0.1550	0.1821	0.2112	0.2424
10	0.0162	0.0272	0.0408	0.0568	0.0752	0.0961	0.1192	0.1447	0.1725	0.2026	0.2350	0.2697
11	0.0178	0.0300	0.0449	0.0625	0.0829	0.1058	0.1313	0.1593	0.1899	0.2231	0.2588	0.2970
12	0.0194	0.0327	0.0490	0.0683	0.0905	0.1155	0.1433	0.1740	0.2074	0.2436	0.2826	0.3243
13	0.0211	0.0355	0.0531	0.0740	0.0981	0.1252	0.1554	0.1886	0.2249	0.2641	0.3064	0.3516
14	0.0227	0.0382	0.0573	0.0798	0.1057	0.1349	0.1675	0.2033	0.2424	0.2847	0.3302	0.3790
15	0.0243	0.0410	0.0614	0.0855	0.1133	0.1447	0.1796	0.2180	0.2598	0.3052	0.3540	0.4063
16	0.0260	0.0437	0.0655	0.0913	0.1209	0.1544	0.1916	0.2326	0.2773	0.3257	0.3778	0.4336

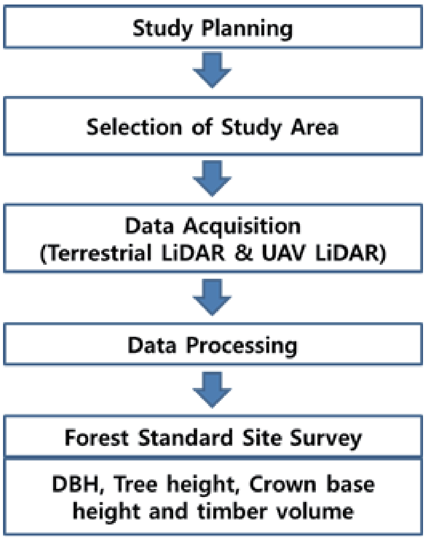

Fig. 1. (Color online) Flow of study.

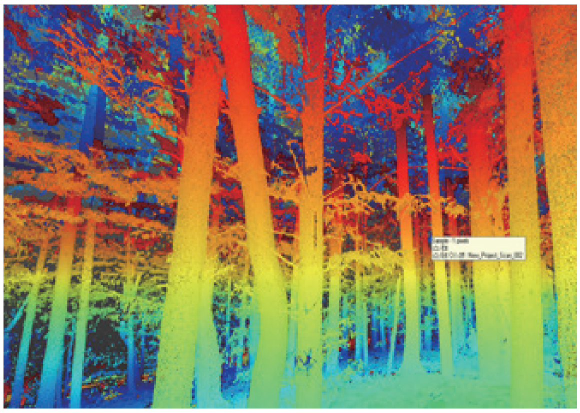

Fig. 2. (Color online) Data acquired by a 3D laser scanner.

$$\rho = \frac{1}{2}c\Delta t, \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \rho\cos\beta\cos\alpha \\ \rho\cos\beta\sin\alpha \\ \rho\sin\beta \end{bmatrix}, \tag{1}$$

where ρ is the distance, c is the speed of light, Δzt is the time difference, x, y, and z are the coordinates of the specific point to be obtained, α is the horizontal angle, and β is the vertical angle.[18]

3. Data Acquisition

In this study, standard land in Gangwon-do was selected as the research subject. The study site is 30 × 30 m^2 and has a total of 20 pine trees. Figure 3 shows the study area.

Data for detecting individual trees were acquired using terrestrial and drone-mounted 3D laser scanners. Figure 4 and Table 2 respectively show the scanners and their specifications.[19,20]

For data acquisition in the forest area, a Trimble X7 terrestrial laser scanner and a Yellowscan SurveyorUltra drone-mounted laser scanner were used. The terrestrial laser scanner acquired data over 60 min from a total of 10 stations, and the drone-mounted laser scanner took 10 min to acquire data. The data acquired by the 3D laser scanner were created as point cloud data with absolute coordinates through data processing. The terrestrial laser scanner data were registered using RealWorks software. Such registration was performed for a total of 10 station data, and one point cloud was created through registration. Since the drone-mounted laser scanner is a mobile device, a point cloud was created by calculating an accurate movement path through trajectory processing, which is the process of calculating the precise position and attitude of a drone using the global navigation satellite system (GNSS) and inertial measurement unit (IMU) mounted on the drone. Additionally, since the drone-mounted laser scanner has absolute

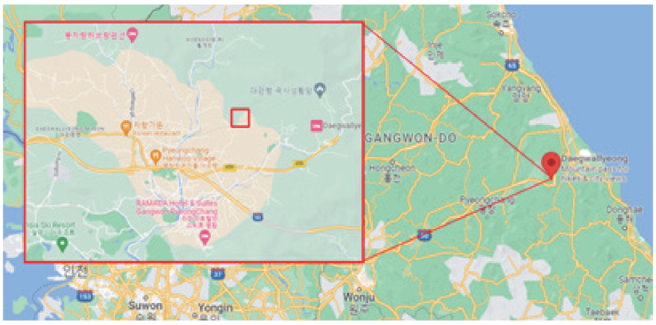

Fig. 3. (Color online) Study area.

Fig. 4. (Color online) Terrestrial and drone-mounted 3D laser scanners.

Table 2
Specifications of the scanners.

Item	Terrestrial light detection and ranging (LiDAR)	UAV LiDAR
Measuring distance	−80 m	−200 m
Scanning speed	500000 pts/s	640000 pts/s
Accuracy	3.5 mm@20 m	3 cm
Field of view	360 × 282°	360°
Weight	5.8 kg	1.32 kg

coordinates, integrated data were created by georeferencing the terrestrial laser scanner data to the drone-mounted laser scanner data. Figure 5 shows the flow of data processing.

The ground was removed from the point cloud built through data processing for forest survey utilization. Figure 6 shows the forest geospatial information with the ground removed.

4. Forest Survey

For forest survey utilization, forest spatial information in the form of a point cloud was used to classify and measure trees by object. Figure 7 shows some of the trees classified by object. Small branches were removed from the trees classified by object to measure the crown height and crown.

Object classification involved classifying each tree by object, with each tree being expressed as a point cloud of a different color, making analysis possible for each object. Measurements for the forest survey were performed using Trimble RealWorks (TRW) software. The measurement items were DBH, tree height, crown, and crown base height, as shown in Fig. 8. Table 3 shows the results of the forest survey.

Through the point cloud data acquired by the 3D laser scanner, it was possible to effectively measure the forest survey items. In addition, the data of the top of the tree acquired from the drone-mounted laser scanner made it possible to measure the crown. In addition, since it is possible to classify objects, it is also possible to measure crowns, which can be used as basic data in research on forests. Figure 9 shows the trees classified by object.

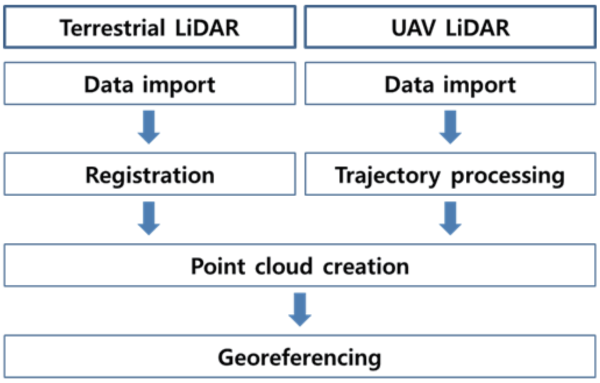

Fig. 5. (Color online) Flow of data processing.

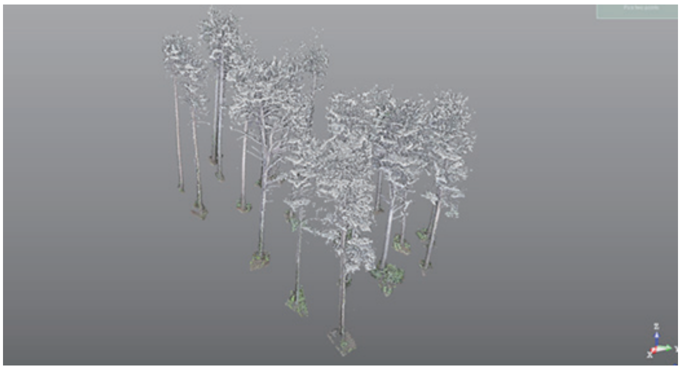

Fig. 6. (Color online) Forest geospatial information with the ground removed.

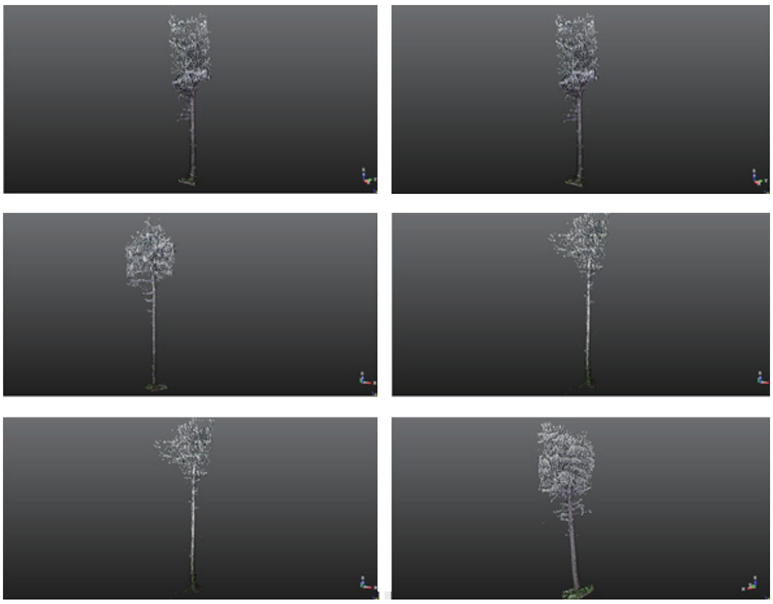

Fig. 7. (Color online) Trees classified by object.

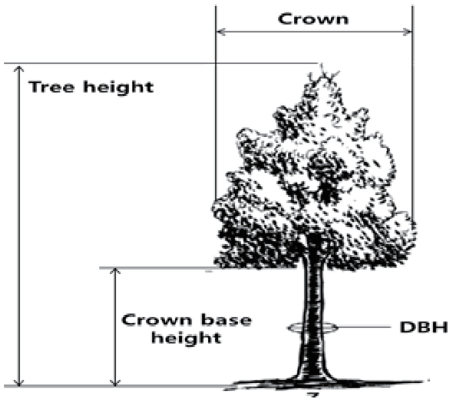

Fig. 8. Measurement items.

Table 3
Forest survey results.

No.	DBH (m)	Tree height (m)	Crown (m)	Crown base height (m)
1	0.4	22.54	3.34	10.82
2	0.44	15.15	2.16	10.82
3	0.37	21.75	2.87	9.22
4	0.44	19.88	3.11	11.14
5	0.34	20.1	2.86	10.86
6	0.37	23.27	2.87	8.88
7	0.42	20.19	3.22	15.56
8	0.48	23.44	3.54	13.28
9	0.32	22.98	2.54	13.16
10	0.5	22.38	3.57	17.79
11	0.55	21.25	3.87	12.62
12	0.44	23.87	3.01	12.12
13	0.55	24.08	3.88	11.49
14	0.5	21.92	3.74	17.37
15	0.59	24.73	4.02	10.94
16	0.39	20.8	2.97	9.65
17	0.37	21.56	2.77	14.31
18	0.48	17.01	3.24	8.89
19	0.53	13.07	3.54	8.91
20	0.5	20.79	3.21	10.2

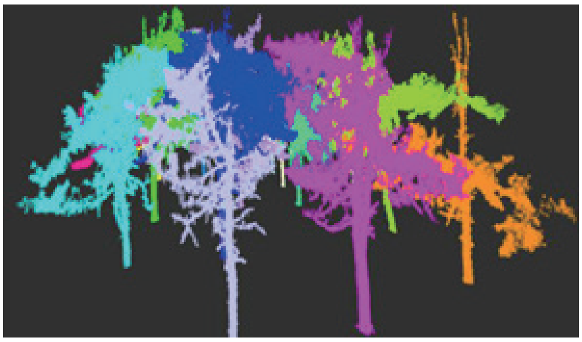

Fig. 9. (Color online) Trees classified by object.

5. Timber Volume Estimation

Currently, the timber volume is calculated from the DBH and tree height using a timber volume table. However, this method has the disadvantage of not properly reflecting the actual volume of the tree. Therefore, in this study, we attempted to accurately calculate the timber volume using point cloud data. Since the shape of the tree is not constant, it is difficult to apply the point cloud method when simply calculating the volume in the vertical direction from the ground. Therefore, the timber volume was calculated by dividing the tree in half, calculating the volume for each half, and summing the two volumes. Figure 10 shows the timber volume calculation process and Table 4 shows a comparison of the timber volumes calculated by the existing method and the method using the point cloud.

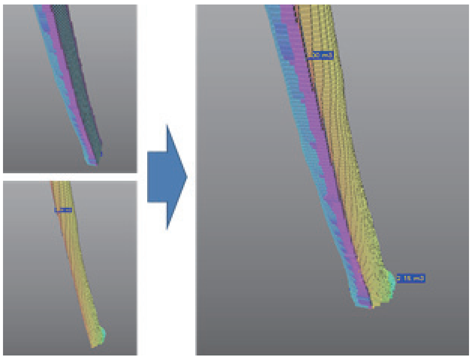

Fig. 10. (Color online) Timber volume calculation process.

Table 4
Comparison of timber volumes.

No.	Existing method (m^3)	Point cloud (m^3)	Deviation (m^3)
1	1.17	1.08	0.09
2	0.95	0.87	0.08
3	1.06	1.05	0.01
4	1.27	1.18	0.09
5	0.78	0.71	0.07
6	1.04	1.01	0.03
7	1.16	1.07	0.09
8	1.80	1.71	0.09
9	0.77	0.68	0.09
10	1.79	1.72	0.07
11	2.22	2.13	0.09
12	1.53	1.46	0.07
13	2.26	2.15	0.11
14	1.79	1.70	0.09
15	2.77	2.71	0.06
16	1.06	1.01	0.05
17	0.96	0.91	0.05
18	1.27	1.18	0.09
19	1.13	1.05	0.08
20	1.70	1.61	0.09
RMSE	0.54	0.54	0.02

The timber volume showed an average difference of 0.07 m^3 between the existing method using a timber volume table and the method using the point cloud, indicating the validity of the method using the point cloud. In the future, it will be possible to determine whether this method can be used in actual work through a comparison with other timber volume calculation formulas. The results derived from this study can be used for forest resource management to improve the efficiency of related tasks.

6. Conclusion

In this study, a forest survey was conducted by acquiring data on trees using a laser scanner and detecting individual trees through processing and analysis. Data on the study site were acquired using terrestrial and drone-mounted laser scanners, and a georeferencing point cloud was effectively created through data processing. DBH, tree height, crown, and crown-based height were effectively measured by removing the ground from the point cloud data generated in the forest area and classifying individual trees. In addition, we suggest that water pipe measurement is possible through the combination of drone-mounted and terrestrial laser scanner data. The existing volume calculation method using a timber volume table and the method using a point cloud were compared. For this comparison, we proposed a method of calculating the timber volume using a point cloud. The timber volume calculation using a point cloud will be applicable to actual forest surveys. In the future, the usability of this method should be evaluated through comparison with other formulas for calculating the timber volume.

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References

1 J. K. Park and K. Y. Jung: J. Korean Soc. Surv. Geodesy Photogramm. Cartogr. **38** (2020) 43. https://doi.org/10.7848/ksgpc.2020.38.1.43
2 H. D. Seo and E. M. Kim: J. Korean Soc. Surv. Geodesy Photogramm. Cartogr. **37** (2019) 405. https://doi.org/10.7848/ksgpc.2019.37.6.405
3 C. B. Park and J. S. Choi: J. Korea Acad.-Ind. Coop. Soc. **22** (2021) 468. https://doi.org/10.5762/KAIS.2021.22.2.468
4 M. S. Do, E. T. Lim, J. H. Chae, and S. H. Kim: J. Korea Inst. Intell. Transp. Syst. **22** (2021) 117. https://doi.org/10.12815/kits.2018.17.5.117
5 J. K. Park and M. K. Oh: J. Korea Acad.-Ind. Coop. Soc. **21** (2020) 411. https://doi.org/10.5762/KAIS.2020.21.12.411
6 H. J. Lee, S. R. Yang, and D. G. Lee: J. Korean Soc. Geospatial Inf. Sci. **29** (2021) 51. https://doi.org/10.7319/kogsis.2021.29.3.051
7 T. W. Kim, S. H. Hong, H. Choi, and K. H. Lee: J. Korean Soc. Geospatial Inf. Sci. **26** (2018) 69. https://doi.org/10.7319/kogsis.2018.26.1.069
8 S. K. Choi, J. W. Choi, S. W. Park, S. H. Jung, and S. K. Lee: J. Korean Soc. Surv. Geodesy Photogramm. Cartogr. **35** (2017) 545. https://doi.org/10.7848/ksgpc.2017.35.6.545

9 J. P. Seo, K. D. Kim, C. S. Woo, C. W. Lee, and H. H. Lee: J. Korea Acad.-Ind. Coop. Soc. **21** (2020) 807. https://doi.org/10.5762/KAIS.2020.21.12.807
10 J. H. Kim and J. H. Kim: J. Korean Soc. Surv. Geodesy Photogramm. Cartogr. **36** (2018) 223. https://doi.org/10.7848/ksgpc.2018.36.4.223
11 J. H. Yoon, E. J. Bae, H. G. Jeon, Y. M. Son, and J. W. Lee: J. Agric. Life Sci. **55** (2021) 55. http://doi.org/10.14397/jals.2021.55.3.55
12 D. Y. Shin, J. H. Han, Y. J. Jin, J. Y. Park, and H. H. Jeong: Korean J. Remote Sens. **32** (2016) 275. https://doi.org/10.7780/kjrs.2016.32.3.7
13 H. S. Lee and S. R. Lim: J. Korean Soc. Environ. Eng. **43** (2021) 377. http://doi.org/10.4491/KSEE.2021.43.5.377
14 S. Y. M. Son, J. H. Jeon, S. J. Lee, J. S. Yim, and J. T. Kang: J. Korean For. Soc. **106** (2017) 450. https://doi.org/10.14578/jkfs.2017.106.4.450
15 Korea Forest Service: Timber Volume, Biomass and Stand Harvest Table, National Institute of Forest Science (Korea Forest Service, Seoul, 2020) 5th ed., Chap. 2.
16 D. E. Gu, J. J. Ku, and S. H. Han: J. Korean Soc. For. **111** (2022) 418. https://doi.org/10.14578/jkfs.2022.111.3.418
17 K. T. Min: Korean J. For. Econ. **29** (2022) 37. https://doi.org/10.31541/KJFE.29.1.4
18 G. H. Moon and J. S. Yim: J. Korean Soc. For. Sci. **110** (2021) 233. https://doi.org/10.14578/jkfs.2021.110.2.233
19 Trimble, X7: https://www.trimble.com/ (accessed December 2022).
20 Yellowscan, SurveyorUltra: https://www.yellowscan-lidar.com/ (accessed December 2022).