Forest 3D Mapping and Tree Sizes Measurement for Forest Management based on Sensing Technology for Mobile Robots

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Abstract This research work aims at application of sensing and mapping technology which has been developed with mobile robotics to equipment measurement of forest trees. One of the key information for forest management in artificial forest is the records of the tree sizes and standing timber volume of a unit area.

The authors made measurement equipment as trial production which consists of small sized laser range scanners with rotating (scanning) mechanism of them. SLAM and related technologies are utilized for the information extraction. In development of SLAM algorithm for this application, sparseness of the standing trees is considered. After the SLAM based mapping based on the data at several measurement points, we can obtain useful information such as a map of standing trees, diameter at breast height of every tree, height at crown base (length of clear bole), and so on.

The authors will report the experiments in the forest and present the map and measured tree sizes.

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1 Introduction

A motivation of this research work arises from necessity of labor-saving in forest mensuration for forest management. The present authors who long have research work in mobile robotics try to apply sensing and mapping technologies into the mensuration. Although the field work of the mensuration is laborious, manual measurement is still undergoing. Of the standard methods for forest survey, a belt transect method (Figure 1) could be employed [1]: e.g., 30m long and 10m wide with a base line running up and down slope in a survey plot. The distance between every tree and the base line for determining tree location, its diameter at the breast height, height at crown base (length of clear bole) and so on are measured within the belt transect. These measurements are performed in manual with measuring tapes by a three person party in standard. Measured parameters are once recorded in a field note by one person, during the other two persons measure the survey items. It takes approximately 30 minutes for a unit area at the earliest. After the measurement, they input the data in an information processing facility.

These data will be processed to obtain standing timber volume and growth rate of forest stands. Such human-intensive manual measurements for forest survey are necessary and common in forest management in the world [2]. Even though remote sensing approach such as airborne measurement with laser profiler has been being utilized [3, 4, 5, 6, 7], it is necessary to establish models of correspondence between every tree measurements in the forest and airborne measured data [8].

A problem for the manual measurement is time-consuming but insufficient to grasp the total environmental resource amount for targeted forests. For example, although Japanese government, as a country engaged in the Montreal Process which aims at sustainable forest management, sets the forest monitoring points of 15 thou-

(a) Diameter measurement with a tape measure (b) Tree location measurement by a party of three persons

Fig. 1 Manual measurement: (a) Measure diameter of each tree within a sampling unit area by a tape measure. (b) Measure horizontal distance from the base line and its location on the base line. Three persons cooperate in tree location measurement.

sands all over Japan, it is said that the number of the monitoring point is not enough to obtain sufficient data for grasping the amount of the forest environmental resource such as biomass or CO_2 absorption. Increasing the number of the point is desired, but it does not offer reality because of insufficiency of budgetary expense to employ enough workers for the mensuration in short time.

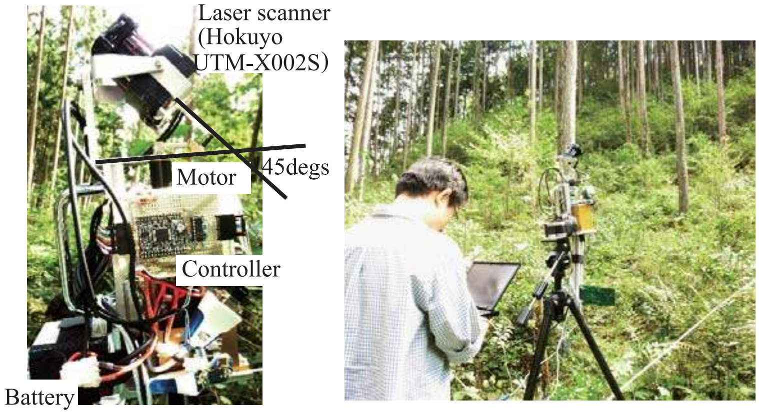
The authors consider that replacing such manual measurements with equipment measurements is a good idea to prompt the forest mensuration. Although airborne approach ([3] and so on) is one method of equipment measurement, it provides rather macroscopic view and will not provide microscopic observation. High cost to hire airplane does not solve the budgetary problem. There are several reports that a laser profiler is used in the forest [8]. However, the profiler itself is also expensive and heavy so that it does not solve the budgetary problem and not have enough mobility.

On the other hand, in robotics field, it becomes very popular to scan the environment by a small sized - light weighted laser scanner on a mobile robot. Such a laser scanner is less expensive than the laser profiler. Furthermore, some appropriate SLAM technologies which are introduced in [9] can be applied to estimate measured locations, to build a map and to assemble point clouds which are obtained by the laser scanner at several measured locations. The authors consider that such sensing and mapping technologies for mobile robots can be applied to the forest mensuration. When we scan the forest by the small laser scanner and obtain point clouds in many location, the assembled point clouds by SLAM will provide shape and arrangement of trees, and will yield data of tree sizes and standing timber volume.

The authors illustrate the desired equipment as a rotating laser scanner at a top of a pole. A person can bring it in the forest. Once the person stands the pole on the forest floor and does three dimensional scan there. The person will iterate such scan at the several points to take three dimensional point clouds in sampling unit area in the forest. Some of the ICP scan matching algorithms such as in [10, 11, 12] are applicable to assemble all the obtained data to produce 3D map of the forest. The authors, however, propose step by step matching algorism taking sparseness of the standing trees into account before the application of ICP in this paper. The proposed scan matching algorithm takes steepness of the slope in the forest into account. Following the illustrated, the authors built up a scanner device and tried to use it in the forest. This paper reports a result of the 3D mapping from obtained data of the rotating laser scanner at several points in the forest and results of diameter measurement of trees in the map.

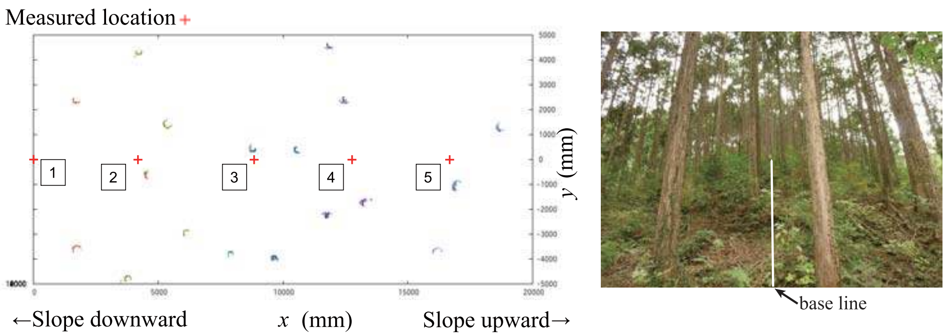
2 A Scanner and Measurement in the Forest

Figure 2 illustrates the scanner device. A small sized laser scanner UTM-X002S of Hokuyo whose planer view angle is 270 degrees (0.6 degrees steps) is employed. The scanner is placed on a stage driven by a motor and a crank (45 degrees) where



(a) Scanner set up (b) Measurement in the forest

Fig. 2 A scanner device is illustrated in (a). An axle of the motor stands vertically followed by a special crank. An axis coincident with laser rotation axle of the scanner will rotate in precession by the rotation of the motor and crank mechanism. (b) The device is deployed for the trial measurement.



(a) Measured locations and point clouds of trunk surface **(b) Measured slope and standing timbers**

Fig. 3 Measured environment and locations in the sampled slope. Measured locations are numbered from 1 to 5.

the authors made use of a mechanism proposed by [13]. This mechanism rotates the center axis which is coincident with the laser rotation axle in precession so that the scanning plane is swayed. In the experiments, the period of stage swaying is 2 seconds. During the one period of the swaying, 200 scans of the laser scanner are performed. The one scan consists of 440 points of the range data. However, 400 points of the range data corresponding to ± 120 degrees from the center of the scanner are used. A coordinate system is defined on the scanner device such that origin is at the base of the device, x axis toward the front, z axis coincide with the motor axle and y axis forms the right hand system. The authors placed the scanner device whose front or x axis of it looks up 15 degrees from the horizontal level by adjusting the lengths of the legs of the tripod. Therefore, the $x-y$plane of the scanner device also has an angle of 15 degrees from the ground.

Figure 3 illustrates the location to scan the environment and obtain point clouds of surface of the trunks in the forest. In the experiment of this paper, the authors set the baseline in the direction of the steepest slope at the sampled area as shown in Figure 3 (b). The steepness of the slope is 30 degrees in average there. The authors set the device from the lowest to the highest location in approximately 5 meters interval along the base line at the slope. The locations where the device is placed are illustrated with '+' and numbered from 1 to 5 in Figure 3 (a). The front of the device is faced to the direction of the base line (Figure 2 (b)).

3 ICP Taking Account of Slope and Sparseness of Standing Trees

For the purpose of so called scan matching, ICP [11, 10, 12] is a popular method to assemble the point clouds of reference and current scans which are obtained at two or more locations after scanning the surroundings by a laser scanner. The authors applied the ICP to the point clouds in planer forest and obtained enough performance for the scan matching [14]. However, when it is applied in the forest with slope, the matching performance in vertical direction may become worse fundamentally because timbers are standing vertically and have less features on the trunk. Separation of point clouds into timbers and undergrowth is also necessary. Therefore, the scan matching process is designed and proposed as follows:

1. extraction of timbers from the point clouds in a current scan and a reference scan,
2. making correspondence among the timbers in the current and the reference scan,
3. extraction of the slope ground level, and
4. applying ICP for the scans.

3.1 Extraction of timbers

First a point cloud density histogram is obtained from a set of scan data of one location by projection onto the $x-y$ plane of the scanner device. However, they are translated onto $\log R, \theta$ plane, where $R = \sqrt{x^2+y^2}$, $\theta = atan2(x,y)$ and (x,y) is at the existing cloud point that z ignored. Figure 4 (a) illustrates an example histogram, where color presents the frequency of the cloud points – green presents low frequency , blue mid and red high. When we see the histogram as a density function of $F(\log R(\theta), \theta)$, high frequency lasts at specific θ for the part of undergrowth. On the other hand, it does not last at specific θ for the part of timber trunk surface. Therefore, a filter is applied to reduce the density if high frequency lasts at specific θ. An example result of the filtering is illustrated in Figure 4 (b), then, the timber trunk surfaces are extracted and identified.

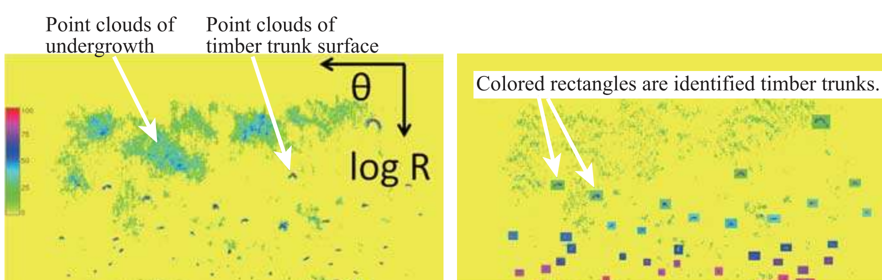
A least square circle fitting is applied to each identified surface of the trunk in the $x-y$ coordinate and center location of the timber is obtained. The plot of such points of the timber center on the $x-y$ plane is named “timber center map”. The timber center map could be see such like constellations which are used for the next step of making correspondence between the constellation of the reference and the current scans.

3.2 Making correspondence among the timbers

In applying ICP, foreknowledge of the correspondence among the same objects in the reference and current scan for beginning the ICP scan matching is helpful to avoid unexpected convergence because of local minima problem. For this purpose, correspondence among the timbers in the timber center map of the reference and current scans must be established [15]. This process seems like to match constellations in the two star charts.

The algorithm to make correspondence among the timbers is summarized as follows (Figure 5) :

1. Take three points of the timber center randomly in the timber center map of the reference scan and form a triangle.
2. Take three points of the timber center randomly in the timber center map of the current scan and form a triangle.
3. Check whether the two triangles are congruent.
4. If the two are congruent, translate and rotate the current map so as to quadrate the triangle in the reference scan with the one in the current scan. Calculate the sum of squared distance between every center point of a timber in the current scan and a point in the reference scan within 100mm of the point of the current scan. Count the number of ’paired’ points to calculate the sum.
5. Iterate 1. to 4. to find smallest sum and larger the number of the paired points in 4.



(a) Point cloud density histogram (b) Separated timber trunk surface

Fig. 4 Separation of point clouds into timber trunks and undergrowth

6. When found in 4., translation and rotation parameters are obtained and the pairs are recognized as corresponding timbers in the reference and the current scans.
7. Use the translation and rotation parameters obtained in 6. as the initial and find most likelihood parameters for them by means of least square method to minimize the sum of distance between paired corresponding timbers in the timber center maps of the reference and the current scans.

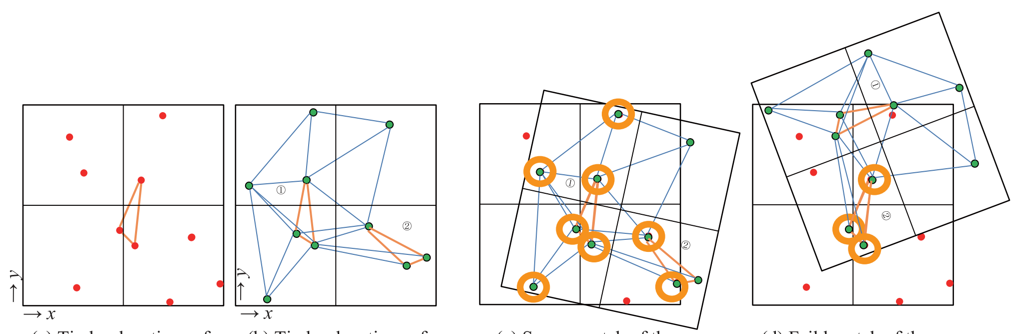
The sparseness of the distribution of the timber centers is considered in the process proposed here.

3.3 Extraction of the slope ground level

For the purpose to obtain good convergence in the z direction, the slope ground level is extracted from the point clouds both in the reference and current scans. The algorithm is summarized as follows:

1. Define a grid in the scanner device $x-y$ plane.
2. Obtain a cloud point such that z coordinate value is the smallest within every square grid lattice, which is a candidate of the ground and not the undergrowth vegetation.
3. Associate all the points obtained in 2 and construct a surface by means of Delaunay triangulation.

Figure 6 (a) illustrates the extracted slope ground level. After the slope ground level is determined, a part of point clouds of the surface of each corresponding timber trunk in the different measured location is extracted at the same height (Figure 6 (b) and (c)). These point clouds are subject to the ICP scan matching in the next Section.



(a) Timber locations of the reference scan
(b) Timber locations of the current scan
(c) Sccess match of the two scans
(d) Faild match of the two scans

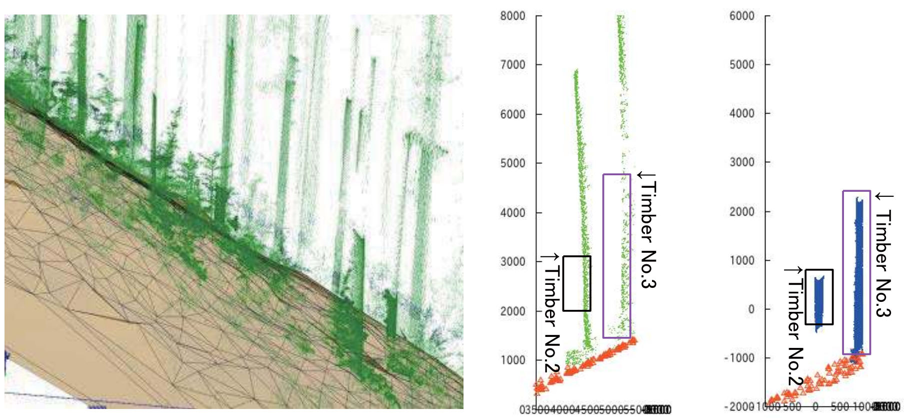
Fig. 5 Making correspondence among the timber centers in timber center map of the reference and the current scans

3.4 Applying ICP

Most steepest descent ICP is applied here. Translation and rotation parameters that are obtained at the step 6 in Section 3.2 are used for initial location to begin the ICP. All the point clouds extracted in Section 3.3 in the reference scan are used, but 60 randomly sampled cloud points extracted in Section 3.3 in the current scan are used for the scan matching once. After convergence to obtain x and y translations and rotations for the tree axes between the reference and the current scan, then obtain z translation to match the slope ground level. Iterate 1000 times for the random samples of the point clouds of the current scan extracted in Section 3.3 and obtain the best converged or minimal residue result. Figure 7 is an obtained 3D map where point clouds measured at locations 1 to 4 in Figure 3 (a). In the right of Figure 7, magnified image of a shrub is illustrated. Observing the branches of the shrub, scan matching in all the translation and rotation components is performed well.

4 Extraction of Tree Data

From 3D map presented in Figure 7, the trunks of the timbers at the breast height from the slope ground level are extracted (Figure 8). Figure 8 (a) presents the point clouds of the trunks and fitted circles on them. This map must be useful for the forest maintenance to yield standing timber volume. Figure 8 (b) illustrates magnified images of timbers of No. 1 and 8 to show how the circle fit on the point clouds. The circle and point clouds on the trunks of timber No. 1 seems to be desired fit. On the other hand for No.8, the point clouds are not necessarily coincides.



(a) Extracted slope ground level after Delaunay triangulation (b) Timber point clouds measured from the location 1 (c) Timber point clouds measured from the location 2

Fig. 6 Extraction of the slope ground level

Table 1 presents comparison of diameters at the breast height between the manual measurement and the proposed equipment measurement. The diameter at the breast height is also important parameter of a timber for forest maintenance. Six timbers of nine have error under 2 cm, other two have in the order of 3 cm and the other has 4.1 cm in error for the diameter. It is said that the desired performance for the error is not more than 2 cm. In this point of view, the proposed equipment measurement achieves in the level of the desired. However, more improvement to reduce the errors is desired.

5 Conclusions

The authors presented necessity of equipment measurement for the forest mensuration and pointed it out that it is good application filed for sensing and SLAM technology for mobile robotics. A experimental setup for mechanically rotating small sized laser scanner is prepared. The setup is operated in the forest and point clouds at several locations are obtained. The authors proposed the step by step scan matching algorithm utilizing ICP taking the existence of the slope and sparseness of the timbers into account. Such equipment measurement in the forest is proved to be ef-

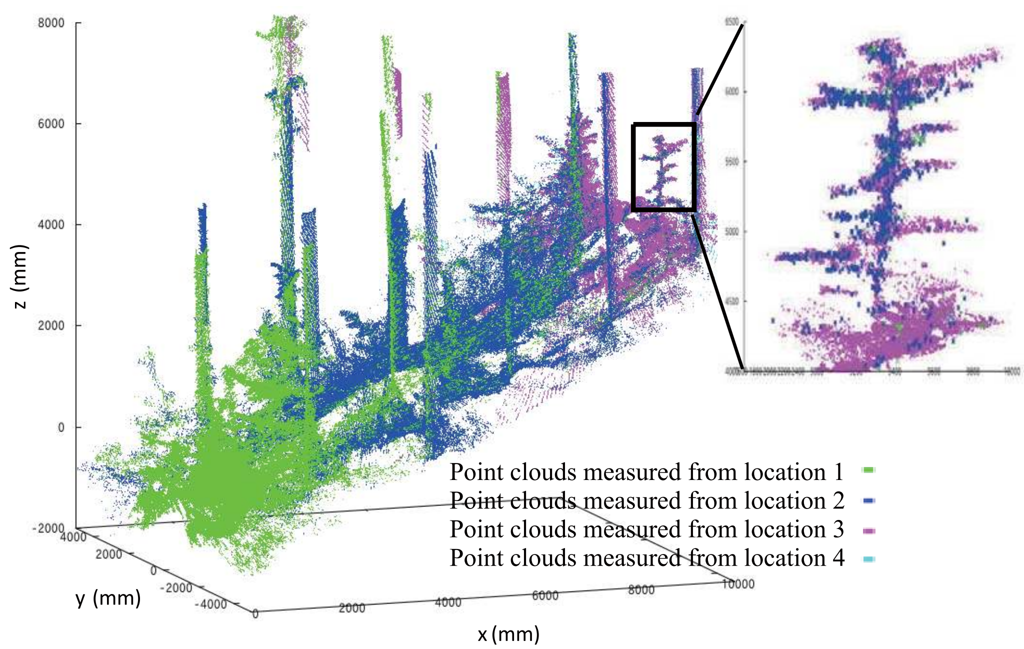
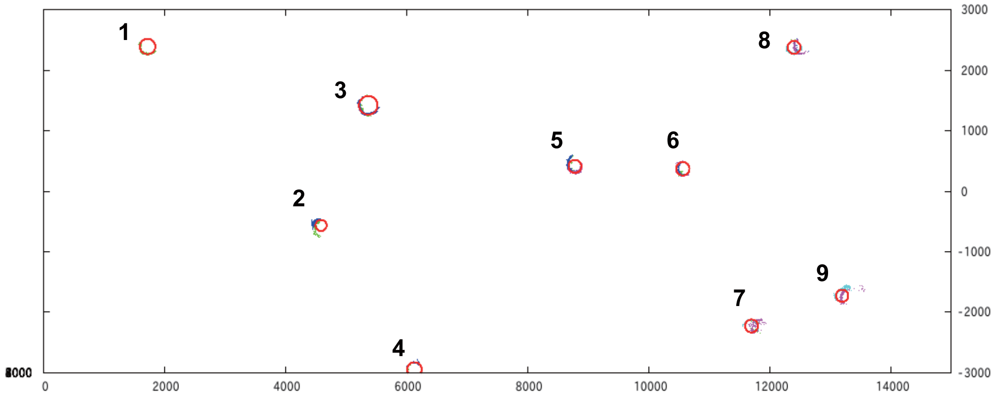
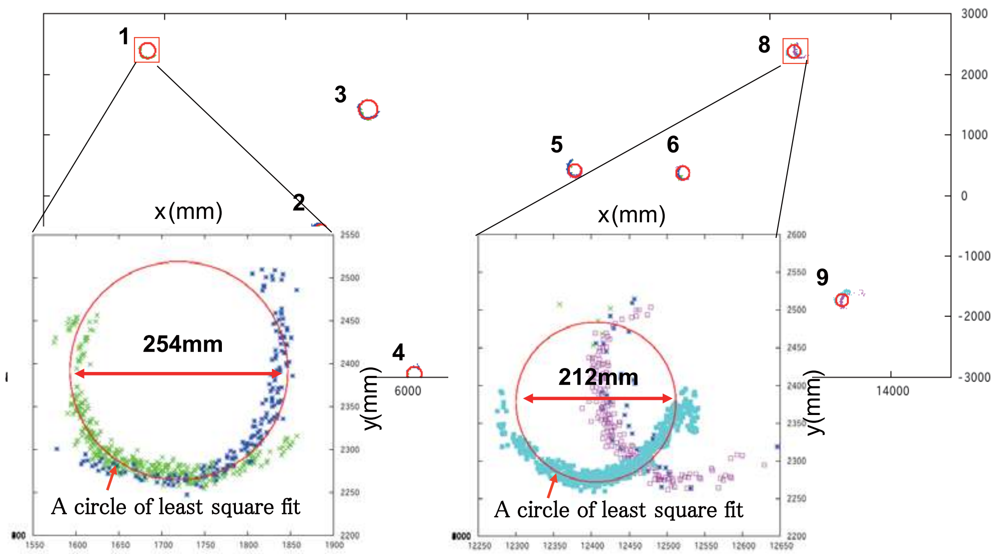


Fig. 7 Example result of ICP scan matching among the 4 locations illustrated in Figure 3 (a)



(a) Timber location map of tranks at breast height



(b) Point clouds of timber number 1 and 8 to illustrate good match and undesired match

Fig. 8 Example result of ICP scan matching among the 4 locations illustrated in Figure 3 (a)

fective, however more improvement is necessary to obtain more accurate data. The improvement is future work.

References

1. Holloway JT, Wendelken WJ (1957) Some Unusual Problems in Sample Plot Design. New Zealand Journal of Forestry, 7(4) 77–83

Table 1 Comparison between manual measurement and proposed equipment measurement for diameter at the breast height

Timber No.	Diameters at the breast height				Standard deviations of the residue of fitted circle (cm)	The number of cloud points
	Manual (cm)	Proposed (cm)	Errors (cm)	(%)		
1	25.8	25.4	−0.4	1.6	0.94	432
2	22.3	18.2	−4.1	18.4	0.78	10750
3	30.1	30.6	0.5	1.7	0.93	2113
4	23	23.8	0.8	3.5	0.99	369
5	24.5	21.2	−3.3	13.5	0.85	11452
6	21.5	22	0.5	2.3	0.82	1257
7	24.6	21.2	−3.4	13.8	1.52	523
8	21.3	21.2	−0.1	0.5	1.54	737
9	21	20.2	−0.8	3.8	0.99	1492

2. Whittaker RH, Bormann FH, Likens GE, Siccama TG (1974) The Hubbard Brook Ecosystem Study: Forest Biomass and Production. Ecological Monographs, 44, 233–254
3. Nelson S, Krabill W, Tonelli J (1988) Estimating Forest Biomass and Volume Using Airbone Laser Data. Remote Sensing of Environment, 24, 247–267
4. Naesset E (1997) Determination of Mean Tree Height of Forest Stands Using Airborne Laser Scanner Data. ISPRS Journal of Photogrammetry & Remote Sensing, 52, 49–56
5. Nilsson M (1996) Estimation of Tree Heights and Stand Volume Using an Airborne Lider System. Remote Sensing of Environment, 56, 1–7
6. Naesset E, Gobakken T (2005) Estimating Forest Growth Using Canopy Metrics Derived from Airborne Laser Scanner Data. Remote Sensing of Environment, 96, 453–465
7. Kato A, Moskal LM, Schiess P, Swanson ME, Calhoun D, Stuetzle W (2009) Capturing Tree Crown Formation through Implicit Surface Reconstruction Using Airborne Lidar Data. Remote Sensing of Environment, 113, 1148-1162
8. Saito R, Tanaka T, Hara H, Oguma H, Takamura T, Kuze H, Yokota T (2009) Aircraft and ground-based observations of boundary layer CO2 concentration in anticyclonic synoptic condition. Geophys. Res. Lett., 36, L07807
9. Thrun S, Burgard W, Fox D (2005) Probabilistic Robotics. MIT Press, Cambridge
10. Chen Y, Medioni G (1991) Object Modeling by Registration of Multiple Range Images. Proc. of IEEE Int. Conf. on Robotics and Automation, 2724–2729
11. Besl PJ, McKay ND (1992) A Method for Registration of 3-D Shapes. IEEE Trans. on PAMI, 14(2) 239–256
12. Rusinkiewicz S, Levoy M (2001) Efficient Variants of the ICP Algorithm. Proc. of the 3rd 3-D Diginal Imaging and Modeling 2001, 145–152
13. Matsumoto M, Yoshida T, Mori T, Yuta S (2009) 3D SOKUIKI Sensor Module by Roundly Swinging Mechanism and SCIP-3D Command System. Transactions of the Japan Society of Mechanical Engineers C 75(760) 3314–3323 (in Japanese)
14. Kondo S, Shiozawa K, Mochizuki T, et al (2010) Three-dimensional Map Building for Forest Structure Analysis Applying ICP. Proc. of the 28th Annual Conf. of the Robotics Society of Japan, 3I3-8 (in Japanese)
15. Kondo S, Shiozawa K, Tsubouchi T, et al (2010) Three-dimensional Map Building for Forest Structure Analysis Using SOKUIKI Sensor. Proc. of the 2010 JSME Conference on Robotics and Mechatronics, 1A1-D16 (in Japanese)