Article

Estimation of Stand Structure in the Deciduous Broad-leaved Forest using Multi-temporal LiDAR Data

Yasuteru Imai^{*1}, Masahiro Setojima^{*1}, Manabu Funahashi^{*1}, Toshio Katsuki^{*2}
and Masahiro Amano^{*3}

ABSTRACT

In this study, we tried to estimate the stand structure of deciduous broad-leaved forest and mixed forest using multi-temporal LiDAR data, and it was compared with field survey result and photo interpretation result. As a result, there is the consistency in LiDAR data obtained the same period and the reproducibility of the DSM is high. In deciduous broad-leaved forest, the amount of changes in the DSM around the defoliation allows us to understand the stand structure such as the covering situation of sub tree and shrub and floor plant. In mixed forest, the multi-temporal LiDAR data is effective for the evergreen tree/deciduous tree classification.

Keywords: LiDAR, DSM, deciduous broad-leaved forest, mixed forest, stand structure

INTRODUCTION

The development of the LiDAR techniques is making progress in recent years, and many attempts have been made to estimate the ground height and the tree height, as well as to extract crowns (PERSSON *et al.*, 2002) and estimate LAI. And there are some reports on new applications in order to understand the stand structure of the forest (SETOJIMA *et al.*, 2003), estimate the snow depth, and classify vegetation etc. Especially, the stand structure of the forest provides useful information that can be used for evaluation of the situation of plantation management, habitat environment of wildlife, and biodiversity.

In this study, we obtained the LiDAR data in multiple

periods. And we calculated the difference in the DSMs (Digital Surface Model) in multiple periods (hereinafter referred to as the “difference method”) to understand the stand structure of deciduous broad-leaved forest and mixed forest with different tree species and management conditions. Furthermore, the result of tree height estimation was used to classify the types of stand structures.

METHOD

Study Area

Target area was set to Tama Forest Science Garden in Tokyo, Japan. And three forests with different tree species and management conditions were selected as the verification areas (see Fig. 1).

- Area A: Well-managed cherry (*Prunus yedoensis*) forest
- Area B: Zelkova (*Zelkova serrata*) forest in natural state
- Area C: Mixed forest

LiDAR Data Acquisition

The LiDAR data used in this study are shown in Table 1. The LiDAR data collected in four periods by a fixed wing airplane were used in this study. The footprint was about 66 cm, and the point density was 0.25 point/m² in all periods.

Corresponding author: Yasuteru Imai

^{*1} Kokusai Kogyo Co.,Ltd. 2-24-1 Harumicho, Fuchu City, Tokyo, 183-0057, JAPAN
(yasuteru_imai, masahiro_setojima, manabu_funahashi)@kkc.co.jp

^{*2} Forestry and Forest Products Research Institute. Matsunosato 1, Tsukuba City, Ibaraki, 305-8687, JAPAN
katsuki@ffpri.affrc.go.jp

^{*3} Waseda University. 2-579-15 Mikajima, Tokorozawa City, Saitama, 359-1192, JAPAN
amano@waseda.jp

Fig. 1 Study sites of this study (Tama Forest Science Garden)

Table 1 LiDAR data used for this study

Date	Flight Altitude (m)	FOV (degrees)	Scan Rate (Hz)	Swath (m)	Density (points/m ²)
2000.10.11	2500	15	20	658	0.25
2001.02.12	2500	16	19.5	703	0.25
2001.12.03	2500	20	24	882	0.25
2002.10.04	2590	15	20	682	0.25

Analysis

Examination of reproducibility of DSM

The difference method focuses on the change in the DSMs accompanying the leaf fall from autumn to winter. It is necessary to confirm that the DSMs of the same season reflect almost the same crown surface (reproducibility). We tried to compare the point clouds in the DSMs obtained two seasons before leaf fall (October 11, 2000 and October 4, 2002) to examine the reproducibility of the DSM.

The point clouds in the DSMs were prepared by extracting only the 1st return pulses from the random points and resampling the points at 2m intervals after interpolation by the TIN (triangulated irregular network).

Estimation of tree height based on DSM before leaf fall and DEM after leaf fall

We prepared the DSM grid in 2m mesh before leaf fall (October 11, 2000) and the DEM (Digital Elevation Model) grid in 2m mesh after leaf fall (February 12, 2001), and the DHM (Digital Height Model) was made after differentiation of the two grids.

The DHM was compared with the result of field survey,

which had been obtained in Area A and a mixed forest similar to that in Area C, to confirm the tree height estimation accuracy.

Understanding the stand structure based on difference in DSMs

We prepared the DSM grids in 2m mesh collected before leaf fall (October 11, 2000), during leaf fall (December 3, 2001), and after leaf fall (February 12, 2001) to find the change in the DSM in each period after differentiation. The DSM change from October to December is called “ ΔDSM_1 ”, the DSM change from December to February is called “ ΔDSM_2 ” and the DSM change from October to February is called “ ΔDSM_3 ”. Every ΔDSM s corresponds to the amount of change in the crown height in each period. After that, we tried to understand the vertical structure (stand structure) in three areas.

Approach to stand structure type classification using DHM and ΔDSM

To achieve the objective classification of stand structures, we attempted to quantitative classify the types of stand structures using both ΔDSM_3 and DHM by thresholding the values.

RESULTS AND DISCUSSION

Examination of Reproducibility of DSM

Table 2 shows the result of examination of the reproducibility of the DSM.

In Area A, the correlation coefficient between the two DSMs with 4,025 points was 0.970, the RMSE (Root Mean Square Error) was 1.334m, and the standard deviation of height difference was 1.327m.

In Area B, the correlation coefficient with 11,010 points was 0.959, the RMSE was 1.546m, and the standard deviation of height difference was 1.493m.

In Area C, the correlation coefficient with 16,936 points was 0.986, the RMSE was 1.417m, and the standard deviation of height difference was 1.399m.

The correlation coefficient was very high in three areas, suggesting that the variation patterns of the DSMs in the two periods were similar. The RMSE and standard deviation of height difference were about 1.5m, which is far smaller than the range of the value of every Δ DSMs. It is considered that the reproducibility of the DSM before leaf fall is high, representing almost the same height (crown height).

Estimation of Tree Height based on DSM before Leaf Fall and DEM after Leaf Fall

Fig. 2 shows the DHM based on the difference between the DSM before leaf fall (October 11, 2000) and the DEM after leaf fall (February 12, 2001). It is assumed that Area B has many high trees of more than 20m in height, Area A has comparatively low trees of 15m in height, and Area C has high and low trees mixed together.

Table 2 shows the result of comparison between the DSM, DEM, DHM and actually measured values. It was found that the RMSE of the DSM was about 1.5-2m, the RMSE of the DEM was about 0.5m, and the RMSE of the DHM was about 1.5m. This result suggested that the DHM includes a difference about 1.5m with respect to the actually measured tree height.

Understanding the Stand Structure based on Difference in DSMs

Fig. 3 shows the Δ DSMs in three periods from before leaf fall till after leaf fall. Since the DHM includes an error of about 1.5m as shown in Table 2, it was considered that the canopy condition didn't change where the Δ DSMs was less than 2m.

Table 2 The evaluation result on the reproducibility of the DSM and the height accuracy of the DHM

	Reproducibility of the DSM				Height accuracy of the DHM					
					DSM		DEM		DHM	
	N	C.C	RMSE	S.D	N	RMSE	N	RMSE	N	RMSE
Area A	4,025	0.970	1.334	1.327	20	1.434	526	0.486	20	1.489
Area B	11,010	0.959	1.546	1.493	-	-	-	-	-	-
Area C	16,936	0.986	1.417	1.399	-	-	-	-	-	-
Mixed Forest	-	-	-	-	15	2.051	314	0.669	15	1.493

N: Number of points, C.C: Correlation Coefficient, RMSE: Root Mean Square Error (m)

S.D: Standard Deviation of height difference of two DSMs (m)

Fig. 2 The DHM of three areas

Fig. 3 Δ DSMs in three periods (before leaf fall till after leaf fall)

Fig. 4 Cross sectional drawing of change in DSMs during the defoliation period

In Area A, the Δ DSM₁ was less than 10m from October to December. From December to February, the Δ DSM₂ was less than 10m in some places, but the number of these places was less composed to that of October to December.

In Area B, the DSM change areas from October to December were observed in all areas except the central area,

and the amount of change exceeded 20m in some areas. From December to February, the DSM change areas were few compared with October to December.

In Area C, many areas were no change, but the DSM change areas were found in patches in three periods.

As a result, it is considered that the Δ DSM₁ corresponds

to cherry trees and zelkova trees that shed leaves early.

Fig. 4 shows the cross section of the change in the DSMs from before leaf fall till after leaf fall (Refer to Fig. 3 for the cross sectional location). It visually shows the condition of low trees and forest floors in the interior of a deciduous broadleaved forest, permitting estimation of the stand structure. In forests where evergreen trees and broad-leaved trees coexist like Area B and Area C, the ΔDSM_s permits clear classification of the boundary between evergreen trees and broad-leaved trees.

Approach to Stand Structure Type Classification using DHM and ΔDSM_s

We tried to classify the stand structure types using DHM and ΔDSM_s by thresholding the values.

Table 3 shows the concept of type classification. Based on the DHM, the dominant tree height was classified. Taking into consideration the error of the DHM, 0-1m, 1-5m, 5-10m, and more than 10m were regarded as the “road and herb”, “shrub”, “sub-high tree”, and “high tree”.

Based on the ΔDSM_s , the condition of the lower layer

was classified. Areas where the ΔDSM_s is 0-1m were regarded as the “evergreen forest” because the seasonal change of the DSM was almost nothing, and the other areas were regarded as the “deciduous forest.” In the deciduous forest, the areas where the same category of the DHM and the ΔDSM_s were regarded as “no lower layer,” the areas where the difference in the two classes were 1-5m were regarded as “herbs in lower layer,” and the difference was 5-10m were regarded as “shrubs in lower layer.”

Fig. 5 shows the result of type classification.

Area A was mostly composed of deciduous high sub-high trees, and the lower layer had nothing or herbs only.

Area B was mostly composed of deciduous high trees, having nothing in the lower layer except the central and northern parts. The central and northern parts were composed of evergreen trees.

Area C was mostly composed of evergreen high/sub-high trees, and deciduous high/sub-high trees were distributed in columns and patches. In the lower layer, nothing or herbs were growing at the bottom of slopes, while herbs or shrubs were growing at the top of slopes.

To validate the result, field survey was conducted and the

Table 3 Concept of type classification of stand structure using DHM and ΔDSM_s

		DHM			
		0~1m	1~5m	5~10m	10m~
ΔDSM_s	0~1m	road and herb	U : shrub (e) L : indistinctness	U : sub-high tree (e) L : indistinctness	U : high tree (e) L : indistinctness
	1~5m	—	U : shrub (d) L : none	U : sub-high tree (d) L : herbs	U : high tree (d) L : shrubs (e)
	5~10m	—	—	U : sub-high tree (d) L : none	U : high tree (d) L : herbs
	10m~	—	—	—	U : high tree (d) L : none

U: upper layer, L: lower layer, (e): evergreen, (d): deciduous

Fig. 5 The result of type classification of stand structure

above result was compared with the cross section (see Fig. 4). As a result, the type classification was almost satisfactory, although the area with “no lower layer” was slightly larger in the classification. In mixed forest, the evergreen/deciduous classification of the high tree layer was correct, and the identification of deciduous broad-leaved trees was comparatively correct.

CONCLUSION

This study was intended to understand the stand structure of deciduous broad-leaved forest and mixed forest based on LiDAR data obtained in four periods. It is also intended to classify the types of stand structures with the help of the information about tree height.

As a result, it was found that there is consistency in the LiDAR data obtained the same period and the reproducibility of the DSM is high; the amount of changes in the DSM allows us to understand the stand structure of the interior of deciduous broad-leaved forest, as well as type classification; In mixed forest, LiDAR data collected in multiple periods are

effective for classification of evergreen trees and deciduous trees.

However, the verification is insufficient at present, and it is necessary to collect the height information of high trees, shrubs, and herbs by field measurement and aerial photogrammetry to conduct quantitative verification of the results of the method described in this paper.

LITERATURE CITED

- PERSSON, A. *et al.* (2002): Detecting and measuring individual trees using an airborne laser scanner. *Photogrammetric Engineering and Remote Sensing* **68**: 925-932
- SETOJIMA, M. *et al.* (2003): Basic study of tree height measurement in Satoyama Coppice Forests and identification of the distribution of deciduous broadleaf trees using airborne laser scanner data before and after defoliation. *Journal of the Japanese Institute of Landscape Architecture* **66**(5): 503-508

(Received 15 January 2007)

(Accepted 17 January 2008)