TREE-HEIGHT MEASURING CHARACTERISTICS OF URBAN FORESTS BY LIDAR DATA DIFFERENT IN RESOLUTION

Y. Imai [a, *], M. Setojima [a], Y. Yamagishi [b], N. Fujiwara [c]

[a] Kokusai Kogyo Co., Ltd. , 5 Sanbancho, Chiyoda-ku, Tokyo, Japan - (yasuteru_imai, mseto)@kkc.co.jp
[b] Organization for Landscape and Urban Greenery Technology Development , 1-21-8 Toranomon,
Minato-ku, Tokyo, Japan - yamagishi@greentech.or.jp
[c] National Institute for Land and Infrastructure Management , 1 Asahi, Tsukuba-shi, Ibaraki, Japan -
fujiwara-n92db@ nilim.go.jp

Commission VII, WG VII/4

KEY WORDS: LIDAR, Urban, Vegetation, Multiresolution, Measurement, Accuracy, Comparison

ABSTRACT:

Urban forests are important as valuable green resources to give moisture and tranquillity of mind in our living, requiring an efficient control of forest increase/decrease and growth rate. In this study, we conducted tree-height measurements using LIDAR data different in resolution at urban parks in the suburbs of Tokyo, and investigated the measuring characteristics. As a result, for conifers, LIDAR data of high resolution (1 m) of high treetop irradiating probability showed higher measuring accuracy. For trimmed broadleaf trees, on the other hand, the LIDAR data of low resolution (2 m) of low penetration probability between branches showed higher measuring accuracy, indicating that the tree-height measuring accuracy by the LIDAR data does not necessarily depend on the resolution.

1. INTRODUCTION

Urban forests are important as valuable green resources to give moisture and tranquillity of mind in our living. In recent years, much attention has been directed to the diversified functions of urban forests such as the contribution to the prevention of global warming through the absorption of CO_2 of plants, mitigation of heat island phenomena by the evapotranspiration of vegetation and disaster prevention effect such as the creation of sheltering space and prevention of fire spread. Especially, high expectation is accorded to the prevention of global warming by CO_2 absorption function of plants in relation to the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP) (Handa & Teshirogi, 2002).

The continuous monitoring of increase/decrease and volume of growth of plants is necessary to promote the conservation and creation of urban forest. To this end, LIDAR is effective means in monitoring wide ranged area, and many studies have been conducted in recent years as the measurement of tree height using LIDAR provide basic parameter of CO_2 absorption volume (Yamagata et al., 2002). However, the measurement of tree height by LIDAR has been mostly conducted at mountain forest, and the case studies at urban forest are rather scarce. In addition, the platform of LIDAR is roughly classified into rotary wing (helicopter) and fixed wing (Cessna) but the study on the comparison of both platforms is very few.

In this study, we measured the tree height of urban forests using the LIDAR data of different acquisition density obtained by rotary wing and fixed wing, and studied their measuring characteristics.

2. MATERIAL

2.1 Study Site and Field Survey

Target area is set to Koganei Park in Tokyo, Japan (Figure 1). The park comprised of area of 77 hectares containing variety of trees with blend of the different combination and density. Study sites area selected from this park because the park contains different types of tree and the ground truths for the verification of those areas are easily obtained by the field survey. Five sites, named St.1, St.2, St.3, St.4 and St.5, are selected regarding to the tree types, the height, and the density. Detail information are shown in the Table 1.

Field surveys are conducted in the all sites on November 5 and 6 of 2002. For each tree, the position, the height, the diameter at breast height, and the species are obtained as the ground truth. The positions and heights of every tree are acquired using the differential GPS (GPS Pathfinder Pro/XR) and the laser measurement instrument (LaserAce300). Information about the diameter at breast height and the species are based on the actual measurement.

2.2 Multispectral Satellite Image

In this study, we used IKONOS data to extract the vegetation area. IKONOS data we used is that obtained on September 21, 2000 and the ortho-corrected multi-spectral (red, green, blue and near infrared) image, and its spatial resolution is 4 m (horizontal accuracy +/- 3.5 m) (Table 2).

---

* Corresponding author.

2.3 LIDAR Data

In Tokyo, the LIDAR data acquired are stored in the form of "library" by the private enterprise, and sold to the general public. In this study, we used the library data of different acquisition density obtained by rotary wing and fixed wing.

The data of rotary wing are acquired by ALMAPS owned by Aero Asahi Corp. on July 26 to 27, 2002 which have been processed as DSM (Digital Surface Model) points group and DEM (Digital Elevation Model) points group of 1 m mesh. As for the details of measurement, the flying altitude of airplane was 1,000 m, pulse rate was 25 kHz, scan rate was 25 Hz and foot print was 0.013 m. The measuring accuracy of scanner is +/- 50 cm for horizontal direction and +/- 15 cm for vertical direction (Table 2).

The data of fixed wing are acquired by RAMS owned by Kokusai Kogyo Co., Ltd. on September 24 to 25, 2001 which have been processed as DSM points group and DEM points group of 2 m mesh. As for the details of measurement, the flying altitude of airplane was 2,590 m, pulse rate was 24 kHz, scan rate was 24 Hz and footprint was 0.66 m. The measuring accuracy of scanner is +/- 30 cm for horizontal direction and +/- 15 cm for vertical direction (Table 2).

In this paper, LIDAR data of 1 m mesh is called the "high-resolution data" and LIDAR data of 2 m mesh is called the "low-resolution data."

3. METHODS

3.1 Extraction of Area Covered by Vegetation

The flow of this study is shown in Figure 2. First of all, we extracted the areas covered by vegetation by calculation of NDVI (Normalized Differential Vegetation Index) using the red band and near infrared band of IKONOS. The threshold value between the areas covered by vegetation and not covered by vegetation was specified as NDVI = 0.1.

3.2 Extraction of Height of Structures on the Ground

We made interpolation by TIN (Triangular Irregular Network) to the DSM points group and DEM points group of LIDAR data and converted them to grid data of 1 m mesh and 2 m mesh. In addition, we added subtraction processing to DSM grid and DEM grid. The processed result is hereinafter called the DHM (Digital Height Model). DHM is the model which indicates the height of ground structures and trees.

3.3 Extraction of Tree Height

We separated the trees and ground structures by clipping DHM in vegetation cover area extracted by IKONOS. This processed result is hereinafter called DCHM (Digital Canopy Height Model). DCHM is the model which indicates the height of tree crown. DCHM of 1 m mesh is shown in Figure 3, and DCHM of 2 m mesh in Figure 4.

3.4 Verification of Measuring Result of Tree Height

We verified the measuring accuracy of tree height by comparing the actually measured and DCHM for each study sites. In addition, we discussed the relationship among the measuring error, tree types and resolution.

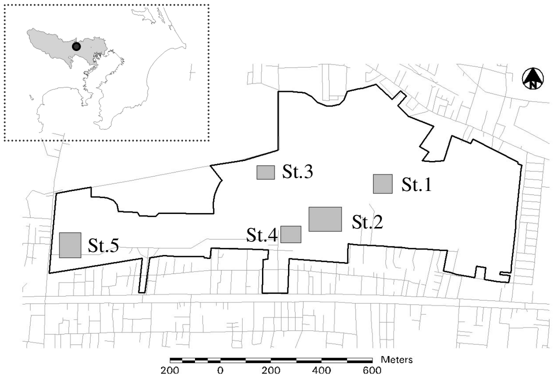

Figure 1. Study sites of this study

St.No.	N	aveH (sdH)	aveD (sdD)	N.S	T.T
St.1	45	10.8 (5.0)	35.0 (17.2)	8	b, m, d
St.2	18	16.5 (3.2)	49.4 (12.5)	3	b, u, s
St.3	21	20.6 (5.3)	55.1 (15.4)	3	c, u, d
St.4	14	13.8 (4.2)	51.5 (15.1)	2	b, u, s
St.5	27	13.5 (3.7)	56.1 (17.2)	1	b, u, d

N: number of tree, aveH: average height (m), sdH: standard deviation (m), aveD: average diameter at breast height (cm), sdD: standard deviation (cm), N.S: number of tree species, T.T: tree types (b=broad-leaf, c=coniferous, m=multi-storied forest, u=uniform forest, d=dense, s=sparse)

Table 1. Detail of ground truth result

Type	Name	Level	S.R	Date
Satellite Image	IKONOS	Multispectral	4m	2000/9/21
LIDAR	ALMAPS	DSM	1m	2002/7/26 - 27
		DEM	1m	2002/7/26 - 27
	RAMS	DSM	2m	2001/9/24 - 25
		DEM	2m	2001/9/24 - 25

S.R: Spatial resolution

Table 2. Data used for this study

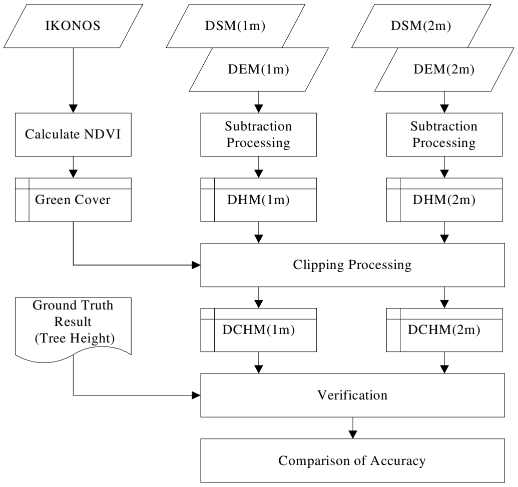

Figure 2. Flowchart of this study

Since both of the IKONOS and LIDAR data used in this study were acquired at the time of luxuriant foliage, we assumed there was no seasonal influence in implementing the verification. Although the year of acquisition was different, we assumed that there was no significant change in the forest areas and hence no time serial influence.

4. RESULTS AND CONSIDERATION

4.1 Measuring Characteristics by Tree Types

The result of accuracy verification is shown in Table 3. There was a tendency that the tree height measured by LIDAR was somewhat lower than the value of actual measurement, and the average error was -2.30 m in the case of high-resolution data and -1.48 m in the case of low-resolution data. As a result of examining the normality of error distribution, the normality of 1 % risk rate was observed for high-resolution data and 5 % risk rate for low-resolution data.

As for the average error by sites, -0.18 m (St.1), -2.28 m (St.2), -2.52 m (St.3), -7.07 m (St.4) and -3.19 m (St.5) in case of high-resolution data and 0.62 m (St.1), -2.67 m (St.2), -4.62 m (St.3), 0.93 m (St.4) and -2.04 m (St.5) in case of low-resolution data. The average error was in negative value in most cases, and it was known that the measurement of LIDAR was a little lower than the actual height, which is coincident with the conventional finding (Naesset, 1997; Friedlaender and Koch, 2000; Setojima et al., 2002).

The result of accuracy verification by tree types is shown in Table 4. When the verification was made by the species of trees, the tendency of lower height than the actual measurement was more conspicuous in the case of coniferous trees than in the case of broadleaf trees. This is reflecting the shape of tree crown, and it is considered that it was difficult for the laser to hit on the top of coniferous tree which has the tree top of sharp shape.

According to the verification by the stratum, the error was smaller in the case of multi-storied forest than the uniform forest. But as to the verification by tall tree / low tree, the average error of low tree story of multi-storied forest showed the positive value indicating that the height was not measured properly. This is considered to be because the laser to low trees of multi-storied forest is intercepted by the tall tree story.

According to the verification by the density, the trend that the height is measured a little lower than actual height was more conspicuous in case of low density forest than the high density forest. It is considered that this is because the laser was transmitted through the branches of low density forest and therefore, it was difficult to identify the tree top.

4.2 Measuring Characteristics by Resolution

It was known from verification result that the difference between high-resolution data and low-resolution data is influenced by the species and density of trees. As for the species of tree, the high-resolution data showed higher accuracy in case of coniferous tree. As stated before, this is considered to be due to a reflection of the difference in the probability of tree top irradiation.

As for the density, low-resolution data showed higher accuracy in case of low-density forest. It is considered to be because the probability that the laser passes through the branches is lower in the case of low-resolution data and therefore the tree top can be identified easier than the high-resolution data as the mesh is coarse and footprint is larger than the high-resolution data.

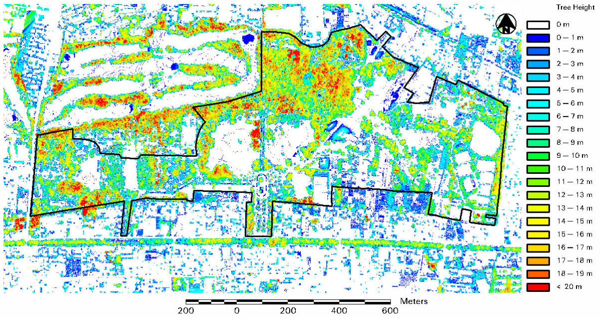

Figure 3. DCHM by high resolution (1 m mesh) LIDAR

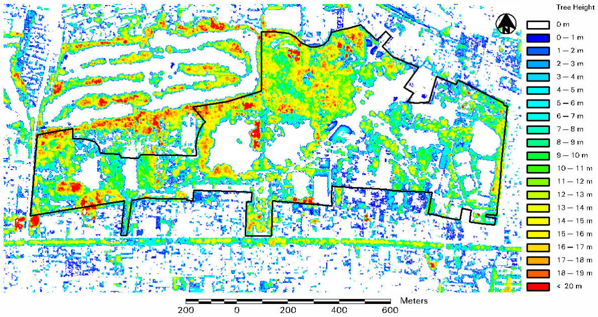

Figure 4. DCHM by low resolution (2 m mesh) LIDAR

St.No.	N	M.E		RMSE	
		H.R	L.R	H.R	L.R
St.1	45	-0.18	0.62	3.74	3.23
St.2	18	-2.28	-2.67	2.72	2.91
St.3	21	-2.52	-4.62	4.45	5.78
St.4	14	-7.07	-0.93	8.58	2.02
St.5	27	-3.19	-2.04	4.59	3.11
All	125	-2.30	-1.48	4.72	3.62

N: number of tree, M.E: mean error (m), RMSE: root mean square error (m), H.R: high resolution LIDAR data (1 m mesh), L.R: low resolution LIDAR data (2 m mesh)

Table 3. Error of tree height measurement by LIDAR

T.T			N	M.E		RMSE	
				H.R	L.R	H.R	L.R
Species	b		104	-2.25	-0.85	4.77	3.01
	c		21	-2.52	-4.62	4.45	5.78
Stratum	m		45	-0.18	0.62	3.74	3.23
		h	24	-1.91	-1.51	2.81	2.62
		l	21	2.28	3.61	4.88	4.76
	u		80	-3.49	-2.66	5.18	3.83
Density	d		93	-1.58	-1.33	4.17	3.92
	s		32	-4.38	-1.91	6.03	2.56
All			125	-2.30	-1.48	4.72	3.62

N: number of tree, M.E: mean error (m), RMSE: root mean square error (m), H.R: high resolution LIDAR data (1 m mesh), L.R: low resolution LIDAR data (2 m mesh), T.T: tree types (b=broad-leaf, c=coniferous, m=multi-storied forest, u=uniform forest, h: high, l: low, d=dense, s=sparse)

Table 4. Error of tree height measurement by tree types

The accuracy of tree top measurement by LIDAR depends on the accuracy of DSM and DEM. Therefore, we compared the DSM and DEM by the resolution, and discussed the factors that give influence on the accuracy of tree height measurement.

Table 5 shows the correlation coefficient between the high-resolution data and low-resolution data of DSM points group and DEM points group at the study sites. As a result, the correlation coefficient of DSM was 0.834 while that of DEM was 0.995, and therefore, DSM had slightly lower correlation coefficient. As the correlation coefficient of DEM was very high, it is considered that there is no large difference in the process of generating DEM from raw data by the difference of resolution.

When the comparison was made by tree types, it was species and density of trees that showed large difference between DSM and DEM. By the species of tree, the correlation coefficient of DSM showed low value (0.372) in case of the coniferous trees, and by the difference of density, that of DSM was showed a slightly lower value (0.744). This is a tendency coincident with the tree height measuring characteristics described before, and it was suggested that the characteristics of DSM was reflected on the characteristics of tree height measurement.

T.T		N	C.C	
			DSM	DEM
Species	b	25,918	0.836	0.996
	c	2,806	0.372	0.818
Stratum	m	4,620	0.928	0.930
	u	24,104	0.813	0.994
Density	d	14,342	0.870	0.997
	s	14,382	0.744	0.827
All		28,724	0.834	0.995

N: number of LIDAR points, C.C: correlation coefficient, T.T: tree types (b=broad-leaf, c=coniferous, m=multi-storied forest, u=uniform forest, h: high, l: low, d=dense, s=sparse)

Table 5. Correlation coefficient of DSM and DEM of different resolution

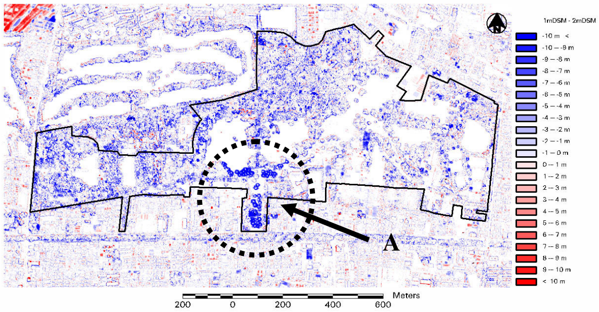

Figure 5. Difference of DSM between high-resolution data and low-resolution data

Figure 6. Picture of site A

Figure 5 shows the difference between DSM of high-resolution data and that of low-resolution data. The areas where the high-resolution data show lower value are indicated in blue color and where the high-resolution data show higher value are indicated in red color. In general, it is known from this figure that there are many more areas where the high-resolution data show lower value. Especially, large estrangement was observed between both DSMs at site A which is sparse Zolkova trees (Figure 6).

5. CONCLUSION

In this study, we measured the tree height at the urban forests using LIDAR data of different resolutions, and discussed the relation between error and tree types and the measuring characteristics by the difference of resolution. As a result, it has become clear that LIDAR tends to measure the tree height lower than actual height as the characteristics that does not depend upon the resolution, and this tendency is conspicuous especially in the case of coniferous trees, and also that the accurate measurement is difficult in the case of low trees in multi-storied forest because the laser is intercepted by the tall tree story. It has also become clear that the accuracy of tree top measurement by the resolution is greatly influenced by the species and density of trees and high-resolution data which have higher probability of tree top irradiation provide the higher accuracy in the case of coniferous trees while the low-resolution data which has low transmission rate through branches show the higher measuring accuracy in case of low density forest. These measuring characteristics of tree top are reflected by DSM, and it was recognized that the measuring accuracy by LIDAR data does not necessarily depend solely on the resolution.

ACKNOWLEDGEMENT

We hereby express our hearty thanks to General Manager, Mr. Toshio Sekiguchi, and Superintendent, Mr. Yoshihiro Yada, of Koganei Park Management Office, Incorporated Foundation Tokyo Metropolitan Park Association.

REFERENCES

Friedlaender, H. and Koch, B., 2000. First experience in the application of laser scanner data for the assessment of vertical and horizontal forest structures. *International Archives of Photogrammetry and Remote Sensing*, 33(B7).

Handa, M. and Teshirogi, J., 2002. Urban forest for global warming prevention - Towards sustainable community - . *Urban Green Technology*, 47, pp.17-21.

Naesset, E., 1997. Determination of mean tree height of forest stands using airborne laser scanner data. *ISPRS Journal of Photogrammetry and Remote Sensing*, 52, pp.49-56.

Setojima, M., Akamatsu, Y., Funahashi, M., Imai, Y. and Amano, M., 2002. Measurement of forest area by airborne laser scanner and its applicability. *Journal of the Japan Society of Photogrammetry and Remote Sensing*, 41(2), pp.15-26.

Yamagata, Y., Oguma, H., Sekine, H. and Tsuchida, S., 2002. The role of remote sensing for monitoring the carbon sink activities. *Journal of the Remote Sensing Society of Japan*, 22(5), pp.494-509.