

Investigation of Measuring Accuracy of Forest Area by Means of Airborne Laser Scanner

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ABSTRACT

It is an important subject to accurately measure forests that serve as sinks since the global warming is taken up as a serious problem in recent years. Tree height and so on have so far been measured by the conventional direct or indirect measuring method. Presently, however, the measuring accuracy by airborne laser scanner has been improved and it is now reaching the stage of practical use for measuring forests as well. For this study, we selected the forest of Tama Forest Science Garden (Hachioji, Tokyo) of Forestry and Forest Products Research Institute as an investigation field where various types of trees grow and a database is constructed. Then we compared the data obtained with the laser scanner with the results of topographic survey and tree height measurement conducted at the investigation field of a specific range and investigated the accuracy of measuring the forest area. According to the verification result relating to the DEM accuracy, the error of the DEM made from the laser scanner to the actually measured value was about 50cm(min.). As a result of accuracy investigation of tree height, a large difference was found in measuring error depending on the growth condition of trees (tree shape). At a place where trees grow almost vertically, the difference between the DSM and tree height value actually measured was small. However, at places where trees grow obliquely or trees are intertwined in a complicated way, the measuring error was large.

1. INTRODUCTION

The interests and expectation of our nation have been increasing to the forest in recent year. Especially, along with the improvement of quality of life and increase of leisure time, diversification of sense of value, recognition of natural environment, and enhancement of orientation towards health and rest, there is an increasingly strong tendency to attempt the sustainable forest management by restoring the places where the human and nature can co-exist through utilization and management of Satoyama coppice forests which have been highly devastated so far. To this end, it is required to make measurement and analysis of forests including those of Satoyama (Shigematsu et al., 1997).

Also, in the various movements in recent years around the Kyoto Protocol as the countermeasure against global warming, a high expectation is accorded to the absorption and fixation function of forest as one of the means to reduce the carbon dioxide among the green house effect gas. Therefore, it has become an urgent issue to establish measurement technology and method for the forests (Oguma et al., 2000 ; Yamagata et al., 2001).

In case where the forest area is selected as the object of study, the

ground height, tree height, tree crown and species can be pointed out as spatially effective information. Sueta applied Fourier analysis to the vertical cross section of ground surface vegetation measured by infrared laser instrument mounted on airplane and assumed the existing volume of vegetation by analyzing the structure of forest over the wide area (Sueta et al., 1998). In this study, the improvement in the accuracy of land surface is pointed out as the future issue. Tamura made an experiment of tree height measurement at Tomakomai experimental plantation of Hokkaido University using airborne laser scanner (Tamura et al., 2000). As a result, the difference between the laser scanner data and actually measured data was in an allowable error of 1m at 67 out of 89 measuring points, namely 75% of the measuring points, and they reported that it was possible to measure the tree height distribution over the wide area with fairly high accuracy. Omasa made 3 dimensional measurement of tree crown height using laser scanner mounted on helicopter (Omasa et al., 2000). In this study, they reported that the difference of crown height between the laser data and actually measured data was 47cm(max.) in case of coniferous trees for which the measuring error is generally large, and 19 cm in case of RMSE.

In our present study, based on the study results on the

applicability of airborne laser scanner, and presuming that this technology is actually used for Satoyama coppice forests, we selected the forest area having the aspects close to Satoyama coppice forests, and verified its applicability to ground surface measurement and tree height measurement based on the data obtained by airborne laser scanner and the analysis made on such data (Funahashi et al., 2001).

2. CONFIGURATION OF THE STUDY

This study is composed of 1) discussion on the ground height measurement and 2) comparison and discussion of tree height measurement (see Fig. 1).

2.1 Discussion on the ground height measurement

The purpose of this discussion was to determine by what extent of accuracy it is possible to assume the ground surface from the data obtained from airborne laser scanner. Namely, we assumed the ground surface by filtering the obtained data and verified the applicability of airborne laser scanner to the ground surface measurement by comparing the data with the results of actual topographic survey. We also compared the data with the ground surface obtained from the existing topographic maps (Tokyo topography at the scale of 1/2500, surveyed in 1999, published by Tokyo City Planning Bureau). The applicability was examined from both comparison and discussion based on ground DEM (we specified the data of airborne laser scanner as LSDSM, those of actual topographic survey as actual measurement DEM, and those obtained from topographic map as topographic map DEM) and comparison and discussion based on the topographic cross section.

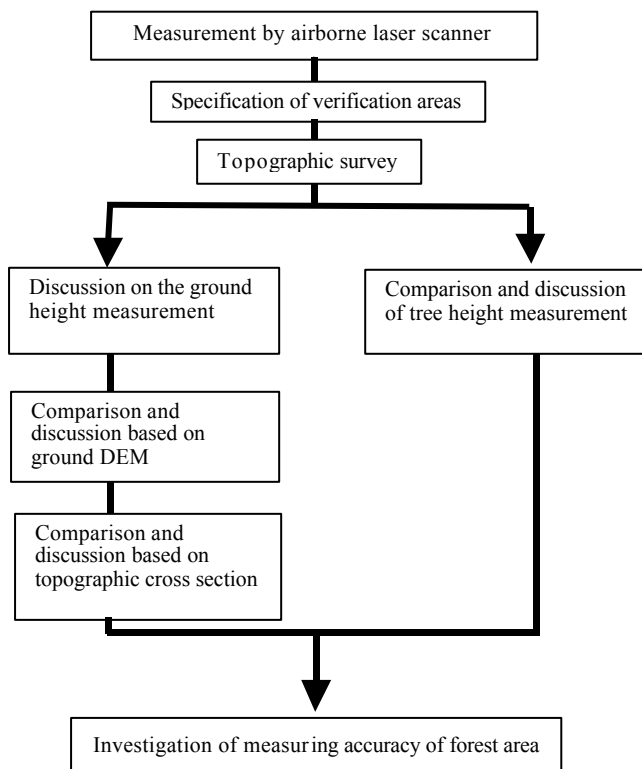


Fig. 1: Structure of the study

2.2 Comparison and discussion of tree height measurement

We compared actual tree height with LSDSM (we specified the first pulse data of airborne laser scanner as LSDSM) and discussed the applicability of this method. As for the applicability, we discussed the influence on the tree height measuring results of the difference of the topography of slope area as well as the difference of composition species (deciduous broad-leaved forest, evergreen/deciduous mixed forest, artificial forest of cedar and cypress).

3. SELECTION AND NOTION OF VERIFICATION AREA

Tama Forest Science Garden of Forestry and Forest Products Research Institute which we selected as the verification area is a hill land of about 57ha with the altitude around 200m located at east edge of mountain mass abutting on Mount Takao in west side of Tokyo. Among this hill land, we specified the verification areas as follows (Photos 1 and 2) considering (1) forest type with different species (cedar artificial forest, deciduous broad-leaved forest, evergreen/ deciduous mixed forest) and (2) different topographic type (steep slope area, gentle slope area and flat area).

ST – 1: This is a steep slope area with dense forest of mature-aged cedar, and one measuring line (A–B section) was specified along the woodland path which runs almost orthogonally against the most steep slope for the comparison of topographic cross section.

ST – 2: This is a area with sparse forest deciduous broad-leaved trees (cherry tree preservation forest), and one measuring line was specified (A–B section) along the direction of most steep slope area for the comparison of topographic cross section.

ST – 3: This is a area composed of flat area and steep cliff on which evergreen/deciduous dense forest is growing. One measuring line was specified (A–B section) on the flat area for the comparison of topographic cross section.

4. MEASURING SENSORS AND OBTAINED RESULTS

4.1 Airborne laser scanner and obtained data

The airborne laser scanner used for this study is RAMS (made by EnerQuest Systems), which can, different from the conventional systems, record maximum 5 reflection pulses against the irradiated laser beam. Monochrome digital camera of 4,096 x 4,096 pixels was also mounted on the aircraft so as to acquire the image data simultaneously with the laser data. The coordinates information of measuring points and picture taking point is recorded at 200Hz by GPS and IMU incorporated in the system. These data enable us to calculate the inclination of digital camera, and make orthophoto without placing ground marks on the land. The measurement by airborne laser scanner was made on October 11, 2000 at the whole areas of Tama Forest Science Garden according to the details as shown in Table 1. Measuring course is

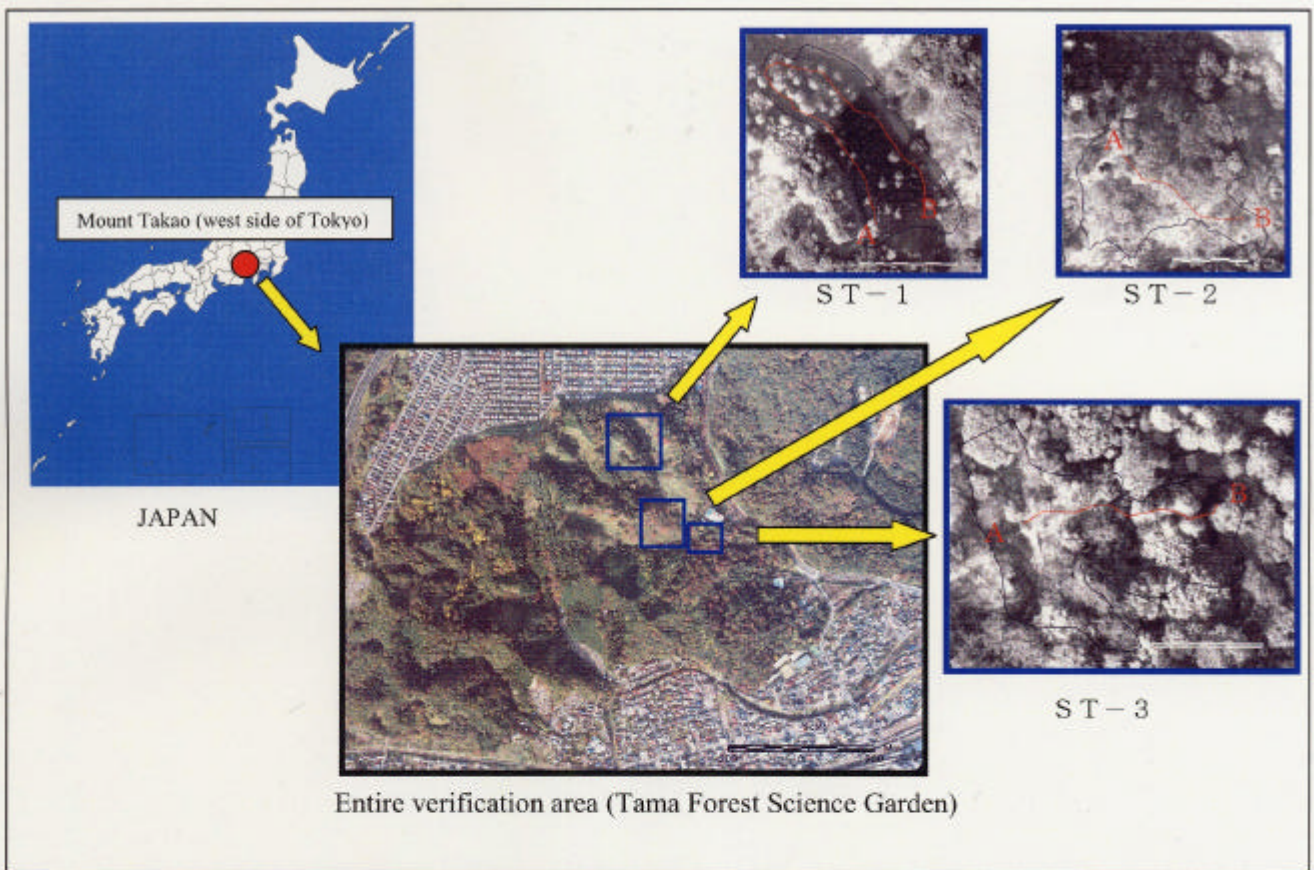
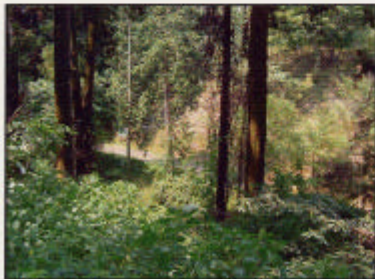


Photo 1: Location of verification areas



ST - 2: Condition at the site (sparse deciduous broad-leaved forest (cherry tree preservation forest), slope area)



ST - 1: Condition at the site (dense cedar forest, steep slope area)



ST - 3: Condition at the site (evergreen/ deciduous mixed dense forest, flat area and steep cliff)

Photo 2: General conditions of verification areas (Tama Forest Science Garden)

shown in Fig. 2 (only the data of verification areas were used in this study). When the data is acquired with these conditions, the width of area which can scanned at one flight is about 650m, and therefore, we made measurement by dividing the area into three courses; the laser irradiation density at this time was 1 laser per 2m square.

4.2 Topographic survey

We made topographic survey in the mid winter (February 8 and 9 , 2001) when the land surface is most exposed. We measure

Table 1: Measuring specifications of airborne laser scanner used for the study

Conditions	Set value
Data acquisition altitude	2500 (m)
Flying speed	200 (km/h)
Scanning angle	15 (deg.)
Scanning width	650 (m)

Table 2: List of measuring instrument used for the topographic survey

GPT – 1002 Topcon	Resolution of telescope	2.5"
	Distance measuring unit (prism)	6,000 m
VERTEX III Timbertech	Measuring distance	30 m
	Measuring range	-55°~ +85°
	Distance resolution	1 cm
	Angle resolution	0.1°
	Height resolution	10 cm

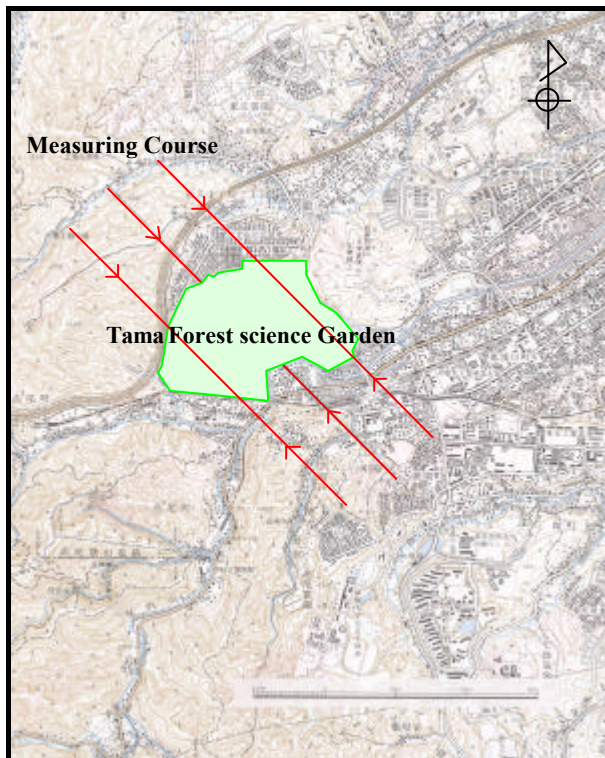


Fig. 2: Measuring course of airborne laser scanner

at the interval of 1m at the places where the topography changed steeply and at the interval of 2m at the places where the topography changed gentle.

We used Total Station (GT – 1002) made by Topcon for the topographic survey and tree height meter (VERTEX III) made by Timbertech for the measurement of tree height (Table 2).

5. RESULTS AND CONSIDERATION

5.1 Discussion on the ground height measurement

In this stage of study, we made consideration both from comparison with ground DEM and comparison with topographic cross section. The actual measurement DEM of 2m interval was interpolated to 1m interval and compared and checked with LSDEM. Especially, we paid attention for the conformity of both DEM's influence by the differences of composition species and shale of slope area. In the comparison of topographic cross section, we analyzed the conformity of topographic cross section obtained from LSDEM, actual measurement DEM and topographic map DEM (made at the interval of 1m) along the measuring lines specified in verification areas ST – 1 ~ 3.

5.1.1 Comparison and discussion based on ground DEM

In ST-1 (Photo 4), there are many points where the difference between LSDEM and actual measurement DEM is within 1m showing relatively high coincidence. However, some fluctuation is observed partially such that LSDEM is rather higher than actual measurement DEM in the north edge of the area while LSDEM is somewhat lower than actual measurement DEM at the central part of the area. It is considered that there is dense forest of matured age trees having large diameter and therefore the laser beam did not reach the land surface being influenced by them, and as a result, LSDEM values were calculated rather higher. Also, the multiple layered forest is formed in this range being dominated by evergreen shrub such as aucuba, which may have given an influence on the calculation results. On the other hand, there is dense forest of juvenile trees at the central part, and therefore, there are only a small number of measuring points where the laser beam can reach the ground surface. In addition, the fine topography could not expressed adequately because many measuring points were erased by the filter processing.

In ST-2 (Photo 3) , the difference between LSDEM and actual measurement DEM is within 1m throughout almost all the area, and the coincidence is highest among three ST's. This is considered because, since this is an area of sparse forest of deciduous broad-leaved trees (cherry tree preservation forest), the laser beam easily reached the ground surface, and also because it is gentle slope area and topography could be adequately express even by the data thinned out by the filter processing. However, there are points where LSDEM differs from actual measurement DEM at a part of north edge of this area. The cause of this anomaly is considered to be that many measuring points were thinned out by filter processing because many trees of large diameter distribute in these points, and the topography is complicated as there is steep cliff at the edge of gentle slope area. In ST-3 (Photo 5), good coincidence is observed between

LSDEM and actual measurement DEM at the west edge of area, but the difference is large at other parts. Especially, ground DEM is calculated higher at south part and north edge and lower at east part of the area. The land surface is almost flat at the west edge of area being occupied by mixed forest evergreen broad-leaved and deciduous broad-leaved trees and the density of tree crown is relatively sparse, which is considered to have resulted in the higher accuracy ground DEM calculation. On the other hand, since tall trees are growing at high density at other parts of this area, the laser beam did not reach the land surface and the topography is complicated being composed of steep cliffs and steep slope, and therefore, the topography was not expressed adequately by the data of measuring points thinned out by filter processing.

It is known from the comparison of results of ST's that there is a difference in the applicability to the compilation of LSDEM by the form of land surface. The applicability is relatively high at the homogeneous topography such flat area in ST-3 and gentle slope in ST-2, while the applicability is rather low at the complicated topography where the change is steep such as steep slope in ST-1 and steep cliff in ST-3. This tendency is especially conspicuous at the place where the density of tree crown is high. This is because only the measuring points where the laser beam reached the land surface are picked up by the filter processing for making LSDEM, and as a result, the number of measuring point that can actually be used is substantially reduced; and DEM obtained by

interpolation is not adequate to express the complicated and steeply changing topography. It is difficult to draw an absolute conclusion as the tendency may vary according to the density of tree crown, but in general, it can be said that the applicability of data of airborne laser scanner to the compilation of LSDEM will be lower as the topography becomes more complicated with steep slope and steep cliff.

It is clear from the comparison of results by ST's that the composition species give a great influence on the applicability to LSDEM compilation. LSDEM coincides fairly well with actual measurement DEM at deciduous broad-leaved forest in ST-2 and mixed forest of deciduous broad-leaved / coniferous trees in ST-3, but the conformity is rather low at a part of ST-1 and ST-3 which is dominated by coniferous forest or mixed forest of deciduous broad-leaved / coniferous trees where the density of tree crown is high. This is considered because the points where the laser beam reaches the ground surface is small at the places of species having high density of tree crown, and the actual topography cannot be adequately expressed by DEM which is created by interpolation. Also, there is a possibility that LSDEM is calculated higher at the places of multiple layered forest such as ST-1 due to the influence of middle ~ low trees. On the other hand, the actual topography was expressed accurately in a part of ST-2 and ST-3 which include deciduous broad-leaved forest probably because the leaf falling had already begun and laser beam reached the land surface at many points. As stated in the

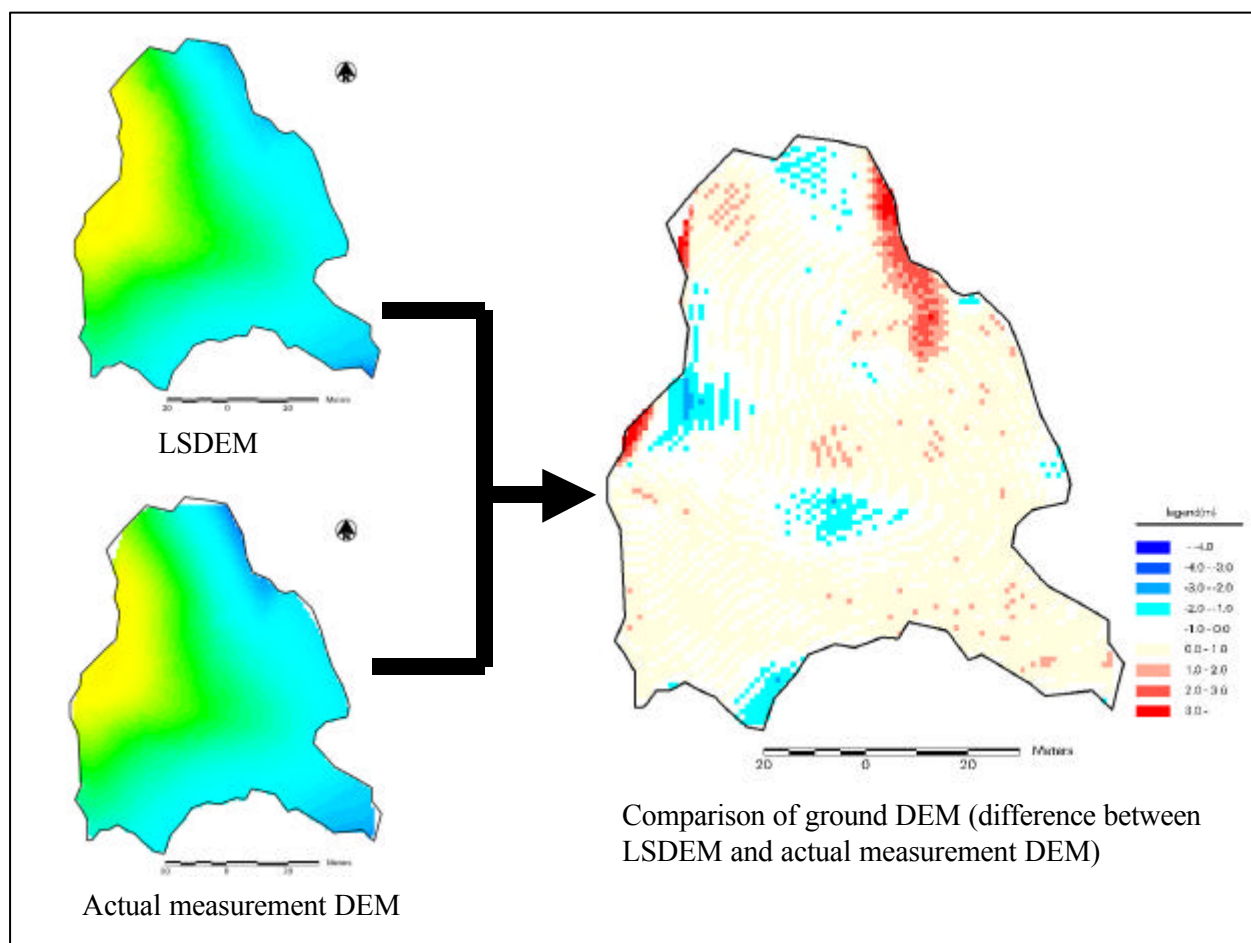


Photo3: Comparison and verification of LSDEM and actual measurement DEM

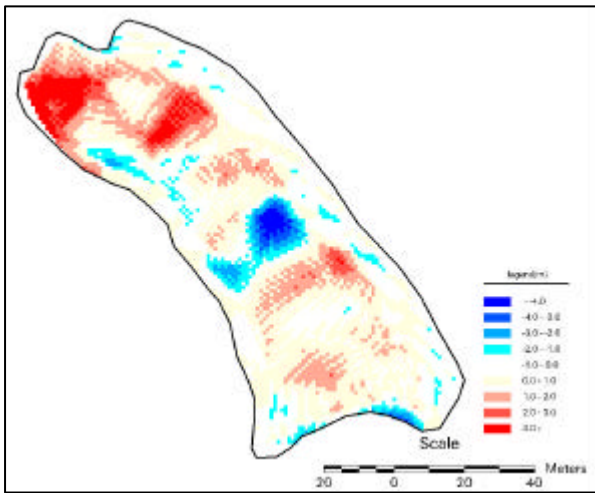


Photo4: Points where there is difference between LSDEM and actual measurement DEM (in case of ST-1)

above, not only the composition species but also the density of tree crown and condition of trees due to the time of survey (season) give influence on the applicability of airborne laser scanner to the compilation of LSDEM.

5.1.2 Comparison and discussion of topographic cross section

The results of comparison of topographic cross section between LSDEM and actual measurement DEM are shown by ST in Figs. 3 to 5. As seen in comparison result of ST-1 consisting of steep slope, a good coincidence is observed between LSDEM and actual measurement DEM with the error of around 1 ~ 2m in general, which is almost the same accuracy of DEM compiled from topographic map. On the other hand, there are points where a large difference in the topographic cross section between the both, but the relationship between its distribution and topography is unknown. As seen in the comparison result of ST-2 consisting of gentle slope, the coincidence between LSDEM and actual measurement DEM is high with the difference within 1m throughout the area, and the land surface is expressed more accurately than those expressed by DEM made from topographic map (topographic map DEM). It is considered that accurate LSDEM can be produced at gentle slope area as there is no difference in the topographic cross section as seen at the steep slope area. In addition, as seen in the comparison result of ST-3 consisting of flat area, it is clear that the shape of land surface is expressed more accurately than those expressed by topographic map DEM similarly as in the case of gentle slope area.

It was understood from the comparison result stated in the above that, in the comparison of topographic cross section, the accuracy of LSDEM is influenced by the topography of study area, and also that it is possible to express the topography more accurately than those expressed by topographic map DEM.

5.2 Comparison and discussion of tree height

The comparison of tree height between airborne laser scanner and actual measurement by ST's is shown in Figs. 3 to 5. In ST-1, the difference of tree height between airborne laser scanner and

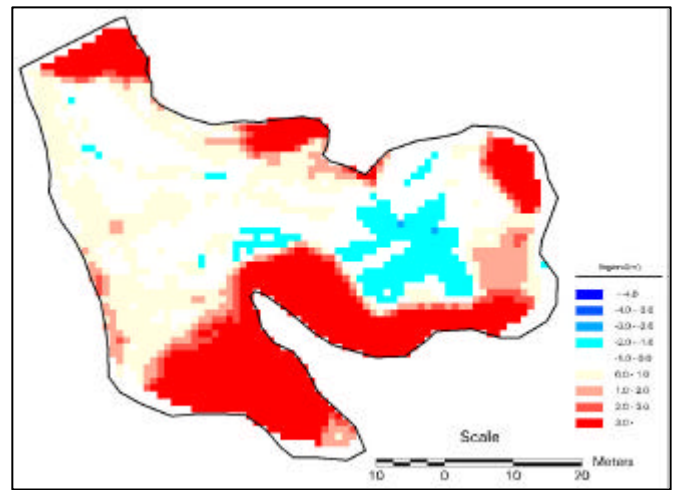


Photo 5: Points where there is difference between LSDEM and actual measurement DEM (in case of ST-3)

actual measurement is 1 ~ 2m showing good coincidence in general. However, there is a tendency that LSDEM is somewhat lower than actual measurement, and when we consider that the height is calculated rather higher by LSDEM comparing with actual measurement, we can understand that the tree height is calculated rather lower. Also, there are some places, although very rare, where tree height calculated by LSDEM is substantially higher than actual measurement; this is considered because the low tree actually measured was concealed by the crowns of surrounding taller tree, which was measured by airborne laser scanner.

In ST-2, it is known that LSDEM coincides quite well with actually measured tree height excepting some exceptional points. Taking into account the good coincidence between LSDEM and actual measurement DEM as stated before, it is considered that the tree height can be measured with high accuracy. On the other hand, the trees are growing upright as shown in Photo 6 in many cases where the tree height obtained by airborne laser scanner coincide with the actual measurement, while the difference is observed between the two in many cases where the trees are growing obliquely (Photo 7).

Similarly to ST-2, LSDEM shows quite good coincidence with the actually measured tree height in ST-3 excepting some parts (Photo 8). Taking into account the good coincidence between LSDEM and actual measurement DEM as stated before, it is considered that the tree height can be measured with high accuracy.

6. CONCLUSION

The outcomes obtained by our present study are summarized as follows:

1) In the spatial comparison of ground height by DEM, it was understood that the applicability of this technique to LSDEM compilation may vary according to the shape of land surface. The applicability to LSDEM is high at gentle slope area or the area having the homogeneous topography, but problems remains for the application of it to the complicated topography including the land having steep cliffs or steep change in the slope.

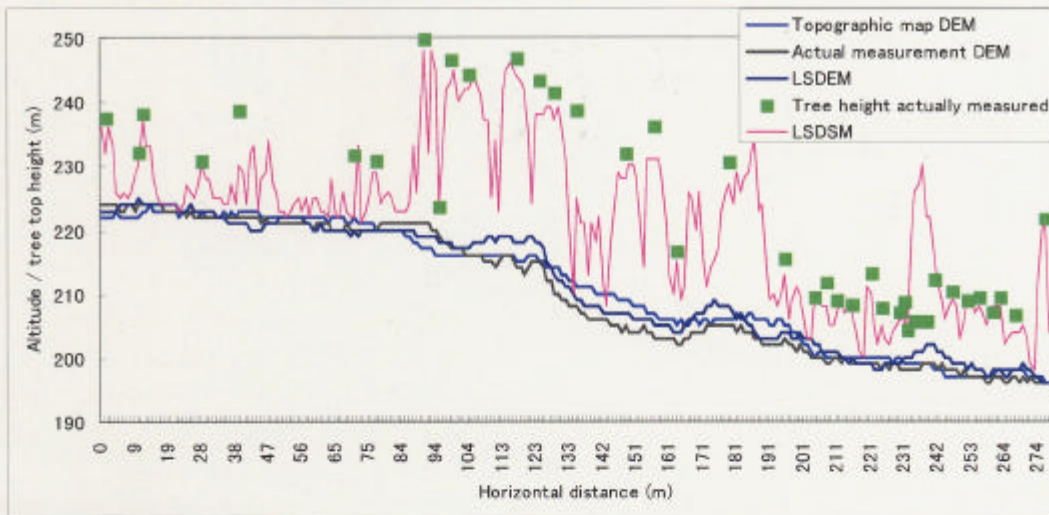


Fig. 3: Comparison of topographic cross section in ST –1

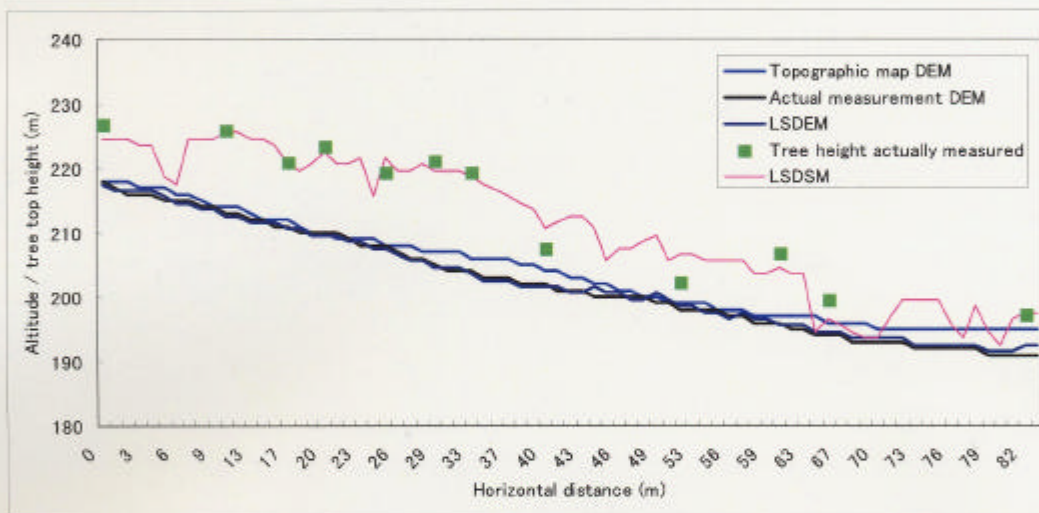


Fig. 4: Comparison of topographic cross section in ST – 2

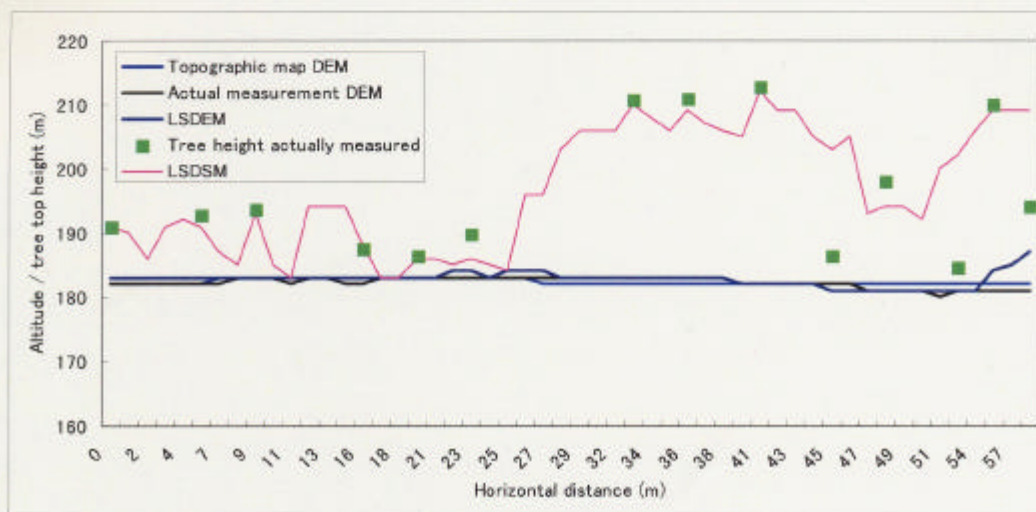


Fig. 5: Comparison of topographic cross section in ST – 3

2) As for the relationship between LSDEM and composition species, the coincidence is high with the actual measurement DEM at the homogeneous deciduous broad-leaved forest and artificial forest where the growth of low layer vegetation is small, but there is an influence of evergreen trees of the low layer at the multiple layer forest where the lower layer is covered by middle and low trees.

3) In the comparison of topographic cross section, there is a tendency that the accuracy of LSDEM is influenced by the topography of study area, but it is considered to be possible to express the topography more accurately than those expressed by existing topographic map DEM at gentle slope and flat area.

4) The conformity with the actual measurement is good in general in the measurement of tree height. Especially the conformity is high at the place where the trees are growing vertically, but the difference from the actual measurement becomes larger where the trees are standing obliquely.



Photo 6: Point of conformity in ST-2



Photo 7: Point of non-conformity in ST-2



Photo 8: Point of non-conformity in ST-3

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