Phyton (Austria) Special issue: "APGC 2004"	**Vol. 45**	Fasc. 4	(497)-(500)	1.10.2005

3-D Measurement of Trees Using a Portable Scanning Lidar

By

F. Hosoi [1)], K. Yoshimi [1,2)], Y. Shimizu [1)] & K. Omasa [1)]

Key words: DEM, DTM, portable scanning lidar, woody tree heights.

Summary

Hosoi F., Yoshimi K., Shimizu Y. & Omasa K. 2005. 3-D measurement of trees using a portable scanning lidar. – Phyton (Horn, Austria) 45 (4): (497)-(500).

Remote sensing is an effective technique for assessing effects of air pollution and global change on forests. Thus, several types of remote sensing, such as Landsat TM and helicopter-borne scanning Lidar have been applied for this purpose. While these techniques were proven to be effective, ground truth measurements are also necessary for determining the precision of remote sensing data. Recently, a portable scanning Lidar has been utilized for more efficient ground measurements of the diameter at breast height (DBH) and carbon stocks of trees.

Accurate 3-D measurement of terrain and woody canopy heights has not yet been fully explored up to the present. Hence, this study demonstrated a technique for estimating terrain and woody tree heights using a portable scanning Lidar. The methodology involved generation of a three-dimensionally DTM (Digital Terrain Model) and DCHM (Digital Canopy Height Model). The detailed procedure was as follows: First, ground and tree canopy were measured from nine points using a scanning Lidar. Second, the acquired data were transformed from polar coordinate to orthogonal one, and then DEM (Digital Elevation Model) for a set of data was estimated. Third, the DEM's obtained at nine points were merged into one DEM. Fourth, DTM was estimated from the merged DEM. Finally, DCHM was generated by subtracting DTM from the merged DEM.

Consequently, DCHM and DTM, which showed exact tree canopy and terrain surfaces respectively, were obtained. The error of DCHM was within 0.34 m and the RMSE was 0.18 m in comparison with results obtained from ground truth data using a range finder.

[1)] The University of Tokyo, Graduate School of Agricultural and Life Sciences, 1-1-1, Yayoi, Bunkyo, Tokyo 113-8657, Japan. Fax: +81-3-5841-8175, e-mail: fumiki1126@yahoo.co.jp

[2)] University of East Asia, Graduate School of Integrated Science and Art 2-1 Ichinomiya-Gakuen, Shimonoseki, Yamaguchi 751-8503, Japan.

Introduction

Remote sensing is an effective technique for assessing effects of air pollution and global change on forests. Thus, several types of remote sensing, such as the Landsat TM (GOWARD & WILLIAMS 1997) or helicopter-borne scanning Lidar (NILSSON 1996, NÆSSET 1997, MEANS & al. 1999), have been applied for this purpose. Recently, spatial resolution has been further improved by the use of scanning lidar with a small footprint and a high repetition rate, mounted on a slow-speed helicopter (OMASA & al. 2000, 2003). While these techniques were proven to be effective, ground truth measurements are also necessary for determining the accuracy of remote sensing data. Recently, a portable scanning Lidar has been utilized for more efficient ground measurements of the diameter at breast height (DBH) and carbon stocks of trees. (OMASA & al. 2002). Information about many trees is acquired simultaneously using a portable scanning Lidar. This advantage can be also applied to tree height measurement. This work aimed to estimate woody tree heights from three-dimensional DCHM (Digital Canopy Height Model) using a portable scanning lidar for more efficient ground measurements.

Material and Methods

A portable ground-scanning lidar (Q140/60; accuracy: ±5 cm, RIEGLE) was used in this study. From the elapsed time between the emitted and returned laser pulses, the lidar can measure the distance to the surface of an object up to 300 m away. The wavelength and repetition rate of the instrument's laser-pulses are 0.9 μm and 12000 Hz respectively. The lidar can scan objects vertically and horizontally by using 4 polygonal mirrors and a rotating mount. Some trees growing in the campus of University of Tokyo were selected and scanned from 5 points on roofs of buildings and from 4 points on the ground in the end of November 2000. These measurement points were arranged about 50-100 m away from the center of the study area and surrounded the trees growing there. Vertical and horizontal scanning angles were set to 60 degree and to 70 degree, respectively. The heights of 20 trees of 5 species were also measured as the ground truth using a range-finder (FG21-HA, accuracy: ±5 cm, RIEGLE) based on a trigonometric survey.

The detailed procedure was as follows. First, the data acquired from a lidar were filtered by 5×5 Median filter to eliminate spike noise. Second, the DEM (Digital Elevation Model) for the set of data was estimated after transforming it from polar coordinate to orthogonal one. Third, the DEM's obtained at nine points were merged into one DEM to compensate the blind regions. In the merging process, based on common points among DEM images, each coordinate of DEM were adjusted to one common coordinate using affine transformation. Only obvious landmarks were selected as the common points among DEM images, i.e. tree tops or the edges of buildings, for more accurate merging. Fourth, DTM was estimated from the merged DEM. The ground points were estimated from the height histogram of a merged DEM, and the missed ground points under trees were interpolated by TIN interpolation method (DAKOWICZ & GOLD 2003). Finally, DCHM was generated by subtracting DTM from the merged DEM.

Results and Discussion

Fig. 1A shows an example of a range image acquired from a certain point. Tree1 in Fig. 1A is the large tree located in central place in the study area. The

DEM images were produced from range images acquired from different positions. Because of one point measurement, each DEM image included blind regions due to canopy obstruction by trees. In addition, the spatial resolution has changed even in the same image because the intervals of laser footprints increased in proportion to the distance between a lidar and objects. 9 DEM images were then merged into one DEM image to compensate blind regions and to decrease the difference of the spatial resolution. This image included fewer blind regions because 9 DEM images were acquired from points surrounding trees. Moreover, the footprint interval was from 5 to 50 mm in this image whereas it was from 5 to 110 mm in the case of Fig. 1A. Since the merged DEM image was composed of several DEM images, each DEM image didn't need to cover long distance. Therefore, difference of footprint intervals in a merged DEM became smaller than the one of DEM obtained from one point measurement.

The height of a merged DEM image is still affected by undulation of the ground. To estimate net tree heights, DTM was produced using TIN interpolating method as shown in Fig. 1B. Although ground surface was obstructed by trees, a DTM could be produced. Fig. 1C and D show DCHM images generated by subtracting DTM from the merged DEM. The net tree heights could be estimated without influence of the ground from a DCHM image.

The error of DCHM was within 0.34 m and the RMSE was 0.18 m comparing with the ground truth. We obtained the ground truth and DEM data almost simultaneously to avoid influence of tree growth. Then, we measured tree heights 6 times per one tree top and these values were averaged to reduce dispersion in each measurement. Therefore, the error may be caused by accuracy of a portable scanning lidar and the error of the merging process.

To confirm that precise estimation could be accomplished using the methodology. Several trees in urban area were measured to verify the results. On these areas, the method has less advantage than the direct measurement using a trigonometric survey, because measuring points can be found more easily and freely. There were also fewer trees that facilitated easier and more direct estimation. The methodology has much advantage in forest region with dense trees. Measuring points are restricted in a forest and the number of trees is very large, therefore it is almost impossible to obtain all tree heights by the direct method. On the other hand, tree heights are obtained in our method if several measuring points can be found there. Then, information about many trees can be acquired as DEM images simultaneously, tree heights are estimated efficiently in spite of numbers of trees.

DCHM and DTM acquired from our method may include more information besides tree heights because these images have fewer blind regions than a DEM image measured from one measurement point. As the next step, the methodology will be applied to a wider region in a forest to take more information such as forest eco-system. We believe that this technique has a big potential and hopefully, can contribute more in the better understanding of forest eco-system.

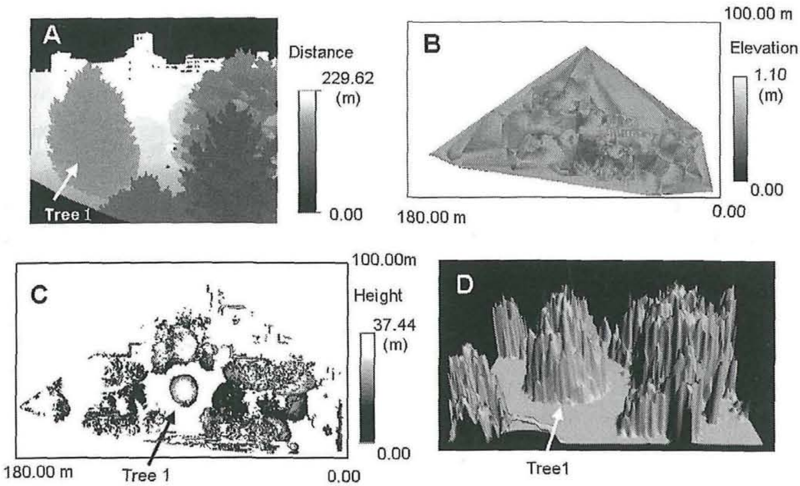

Fig. 1. Results of 3-D measurement of trees using a portable scanning lidar. (A) A range image acquired from only one point. Distance of 0 m or more than 300 m is represented as black color. Tree 1 was the large tree located in the center of the study area. (B) DTM (Digital terrain model) image. This image shows undulation of the ground. (C) DCHM (Digital Canopy Height Model) image. Net tree height can be estimated from the image. (D) 3-D view of DCHM image.

References

DAKOWICZ M. & GOLD C. 2003. Extracting meaningful slopes from terrain contours. - Int. J. Comput. Geom. Appl. 13 : 339-357.

GOWARD S. N. & WILLIAMS D. L. 1997. Landsat and earth systems science: development of terrestrial monitoring. - Photogramm. Eng. Remote Sens. 63: 887–900.

MEANS J. E., ACKER S. A., HARDING D. J., BLAIR J. B., LEFSKY M. A., COHEN W. B., HARMON M. E. & MCKEE W. A. 1999. Use of large-footprint scanning airborne lidar to estimate forest stand characteristics in the Western Cascades of Oregon. - Remote Sens. Environ. 67: 298-308.

NÆSSET E. 1997. Determination of mean tree height of forest stands using airborne laser scanner data. - ISPRS-J. Photogramm. Remote Sens. 52: 49–56.

NILSSON M. 1996. Estimation of tree heights and stand volume using an airborne lidar system. - Remote Sens. Environ. 56: 1-7.

OMASA K., AKIYAMA Y., ISHIGAMI Y. & YOSHIMI K. 2000. 3-D remote sensing of woody canopy heights using a scanning helicopter-borne lidar system with high spatial resolution. - J. Remote Sens. Soc. Japan. 20: 394-406.

— , URANO Y., OGUMA H. & FUJINUMA Y. 2002. Mapping of tree position of *Larix leptolepis* woods and estimation of diameter at breast height (DBH) and biomass of the trees using range data measured by a portable scanning lidar. - J. Remote Sens. Soc. Japan. 22: 550-557.

— , QIU G. Y., WATANUKI K., YOSHIMI K. & AKIYAMA Y. 2003. Accurate estimation of forest-carbon stocks by 3-D remote sensing of individual trees. - Environ. Sci. Technol. 37: 1198-1201.