Application of LiDAR and Digital Aerial Photograph for precise forest inventory

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Abstract

The objective of this study is to explore the feasibility of estimating individual tree level biophysical characteristics(locations, height, crown height, crown width, and DBH) and standwise biomass using LiDAR. Each estimated variable is compared to the field measurements to validate the results. The heights of individual trees are also close to measured height value through R-square value of 0.66. DBH could be predicted by height using DBH-Height Function which was fitted with sample data. Accuracies of predicted DBH by species were R^2=0.73 in *Pinus koraiensis*, R^2=0.73 in *Larix leptolepis* and R^2=0.85 in *Quercus* spp.. Accuracy of predicted Basal Area evaluated with DBH were R^2=0.82 in *Pinus koraiensis*, R^2=0.92 in *Larix leptolepis* and R^2=0.95 in *Quercus* spp.. Stand volume and Biomass were computed by species. The volume and biomass of *Pinus koraiensis* stands with 33ha had about 61,070_/ha and 40,306tdm/ha. The volume and biomass of *Larix leptolepis* stands with 10ha presented about 111,884_/ha and 94,150tdm/ha. In addition, the volume and biomass *Quercus* spp. stands with 37ha include about 79,610_/ha and 94,481tdm/ha.

1. Introduction

Effective forest management is essential because the ratio of forest area is about 62.5% in South Korea. Especially, as Kyoto Protocol is fermented at February 11th 2005, carbon emission trading impacts on national economic policy. Therefore quantitative and qualitative analysis of forest structure is needed for precise forest survey and scientific forest management. Differently from existing remote sensing, LiDAR(Light Detection And Ranging) remote sensing can measure height of trees because of measuring either surface of forest vegetation and terrain in forest area. Therefore it is very useful for surveying forest area that LiDAR is able to analyze of quantitative and qualitative for forest area.

2. Materials and method

2.1. Study Area

A study area is upper left 127°29_0.19380_E, 37°36_16.43433_N and down right 127°30_1.10_E, 37°35_42.94_N around Mt. Yumyeong in Korea. Test sites are 15 plots set up each 10m_10m size in *Pinus koraiensis, Larix leptolepis and Quercus* spp. stands. These test sites were selected due to the fact that structure of tree species is simple and individual tree location is apart from each other.

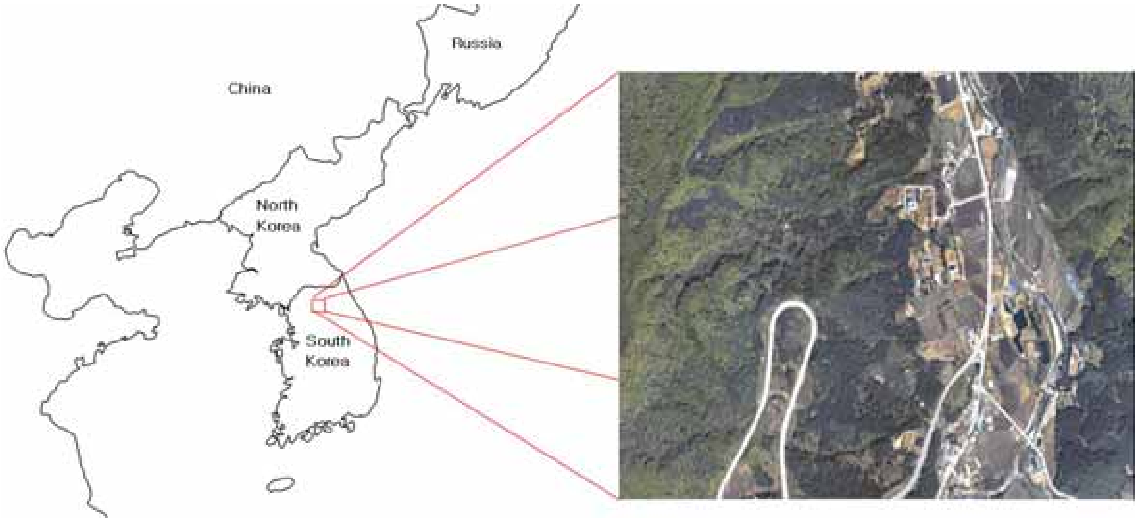


Figure 1. Study area

2.2. Study Materials

2.2.1. LiDAR Data and Digital Aerial Photograph

LiDAR data has 20±10_ spatial resolution(1.8point/_) acquired on 3,000m altitude and digital aerial photograph has 20±10_ spatial resolution with red, green and blue band. Both LiDAR data and digital aerial photograph were obtained at April 2005.

2.2.2. Ground Data

Test sites were composed with 15plots by 100_ per 1plot. 137 individual trees were measured with *Pinus koraiensis*(47), *Larix leptolepis*(46) and *Quercus* spp.(43) individual trees(*Quercus mongolica* and *Quercus variabilis*). Survey items were DBH(Diameter at Breast Height) and height and clear-length height of Individual trees. And each position information of individual trees were acquired at breast height of individual trees using GPS Pathfinder Pro XR manufactured by Trimble Company.

3. Study Method

3.1.Estimation of tree height and Clear-Length height Using LiDAR

LiDAR data of forest stands is classified by High Vegetation Pulse(HVP) reflected on the highest of vegetation, Medium Vegetation Pulse(MVP) reflected on the end of the crown, Low Vegetation Pulse(LVP) reflected near the ground and Ground Pulse(GP) reflected on the ground(Last Pulse). Heights of tree were estimated through positions of individual tree and distance between DSM_{max} from HVP *and* DSM_{min} from GP. Position of individual trees on each DSMs were estimated by elevation values of point data measured at test site. Clear-Length Height is estimated by distance gap between survey point on DSM_{min} and either DSM_{medium} or DSM_{low}. Accuracy of tree height and Clear-Length Height was evaluated by linear regression.

3.2. Estimation of DBH Using Ground Data

DBH of individual trees can be estimated by tree height measured in LiDAR data because DBH-Height Curve Functions were used to estimate DBH. Parameter of each function can be estimated by nonlinear regression analysis using DBH and tree height of individual trees acquired at test site.

Table 1. DBH-Height Curve Functions

No	Function Name	Function
1	Combined Exponential and Power Function	$DBH = a \cdot H^b \cdot c^H$

2	Power Function	$DBH = a \cdot H^b$
3	Exponential Function _	$DBH = a \cdot e^{b \cdot H}$
4	Exponential Function _	$DBH = e^{a - b \cdot H}$
5	Exponential Function _	$DBH = a \cdot e^{\frac{b}{H}}$
6	Exponential Function _	$DBH = a \cdot b^H$

DBH : Diameter at Breast Height(m),
H : Height of tree(_), *a, b, c* : Parameters

Accuracy of each function was validated to use Fitness Index(table 2). Estimated parameters were approved by RMSE(Root Mean Square Error) and T-test. DBH-Height Curve Functions were excepted unless evaluated functions were suitable for general growth pattern.

Table 2. Fit statistics for evaluating performance of stem taper function

Statistics	**Equation**
Fitness Index(FI)	$FI = 1 - \sum_{i=1}^{n} (Y_i - \hat{Y})^2 / (Y_i - \overline{Y})$
Mean Square Error(MSE)	$MSE = \sum_{i=1}^{n} (Y_i - \hat{Y})^2 / (n - m)$

n : number of observation
m : number of parameter used in the estimation
: observed diameter, : predicted diameter

3.3. Computation of stands volume and biomass using LiDAR and digital aerial photography

3.3.1. Segment based classification by Maximum likelihood method

Pixel based classification of tree species using high resolution digital aerial photograph and satellite imagery causes Salt and Pepper Effect that mixed land cover type. As the unit of classification, segments created with maximum likelihood method were used in this study because it is effective method that classifies high resolution imagery using Segment Based Classification(Chong, 2003). Digital aerial photography was segmented by Region Growing Method that was to define heterogeneity of image object and then last segment imagery was classified using Maximum likelihood method.

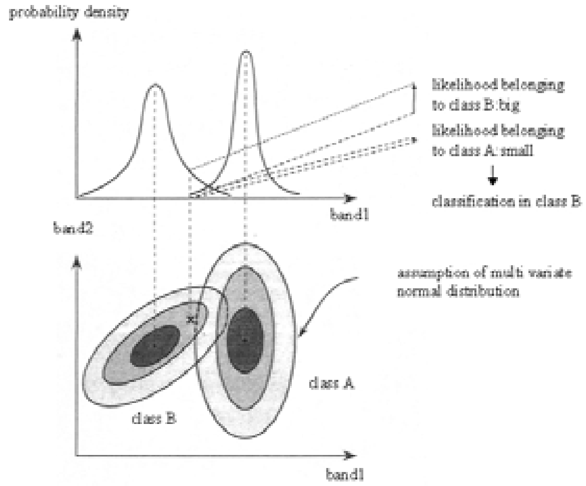
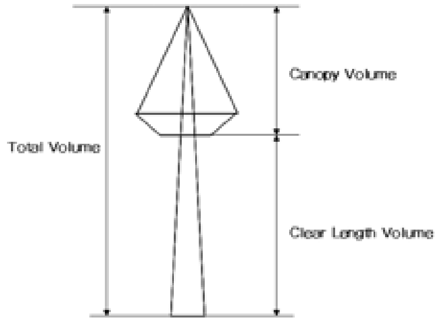


Figure 2. Concept of Maximum likelihood Method



$$CLV = 0.8 \cdot \pi \cdot (\frac{DBH}{2})^2 \cdot CL$$

$CLV =$ Clear-Length Volume

$CL =$ Clear-Length

Figure 3. Volume calculation

3.3.2. Computation of stands volume

Total volume of study area(stands) is expressed with the sum of canopy volume and stem volume. Canopy volume was computed with TIN(Triangular Irregulated Network) made of HVP and MVP to be able to calculate Clear-Length Height. Clear-Length Height Volume can be computed by multiplying 0.8 to consider decreased rate of stem after assuming DBH to radius of stem and clear-length to height of stem length.

3.3.3. Computation of biomass

Methods to estimate biomass equations are two that use single tree and stand. Equation of single tree biomass has one parameter validated in the existing study(Kim *et al*. 1998) and two variables which is DBH and tree height. Therefore if DBH and height of tree are measured, single tree biomass will be evaluated. Stand biomass is computed with only stand volume although equations have three parameters because oven-dry gravity B and parameter C were calculated by researcher.

Table 3. Equation of Biomass Estimation

Single Tree Biomass	**Stand Biomass**
$Y = a \cdot D^2 \cdot H$ a: Parameter D : DBH H : Tree height	$Y = A \cdot B \cdot C$ A : Stand volume(_) B : Oven-dry gravity(tdm/_) C : Parameter

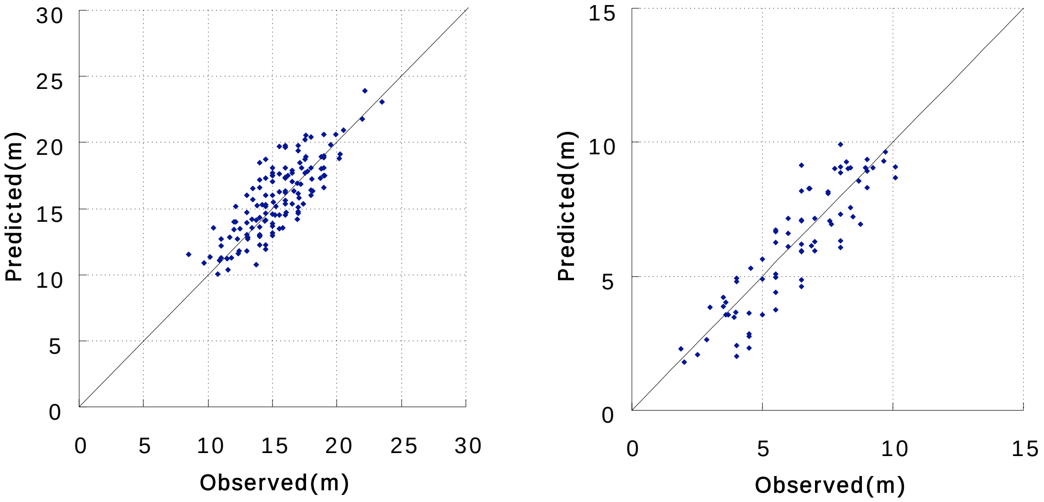
Table 4. Parameters of estimated species

Unit	**Parameter**	***Pinus koraiensis***	***Larix leptolepis***	***Quercus* spp.**
Single tree	a	0.024250	0.026211	0.026849
Stand	B	0.40	0.51	0.69
	C	1.65	1.65	1.72

4. Result

4.1. Evaluation of accuracy with Tree height and Clear-Length Height

R-square of tree height by total species of study area was 0.66. R^2 about *Pinus koraiensis* was estimated at 0.68, *Larix leptolepis* at 0.68 and *Quercus* spp. at 0.60.



Height Accuracy of Total Species

Clear-Length Height Accuracy of Total Species

Figure 4. Accuracy analysis of height of tree by three species

Clear-Length could be calculated by MVP since pulse range was 1.139~9.913m and its R^2 about total species was estimated at 0.79 . By species, R^2 of *Pinus koraiensis* was 0.76, *Larix leptolepis* 0.79 and *Quercus* spp. 0.68.

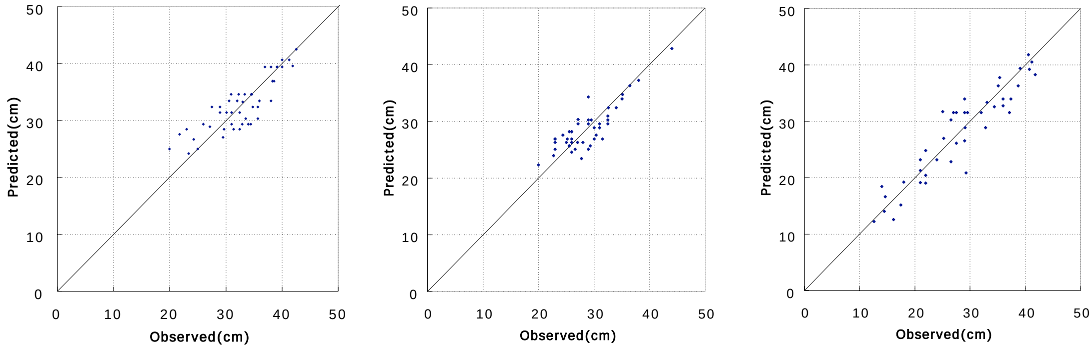
4.2. Estimation of DBH and evaluation of accuracy by tree species

Exponential Function _ of six equations is the most suitable for calculating DBHs by three tree species. The other equations were excepted because statistics values were not fitted or appropriate for general growth principle. Each fitness index is that *Pinus koraiensis* was estimated 0.9927, *Larix leptolepis* 0.9933 and *Quercus* spp. 0.9857.

Table 5. Statistics in nonlinear regression analysis of total species

	Function	FI	Parameter	Estimate	Std. Error	T	Pob>|T|	$\sqrt{MSE}$
Pinus koraiensis	Exponential Function _	0.9927	*a*	11.4296	1.1428	10.0014	0.0001	2.8979
			b	1.0673	0.0064	167.0266	0.0001	
Larix leptolepis	Exponential Function _	0.9933	*a*	13.4179	0.9366	14.3261	0.0001	2.4389
			b	1.0475	0.0042	247.6359	0.0001	
Quercus spp.	Exponential Function _	0.9875	*a*	8.0521	0.7672	10.4954	0.0001	3.3931
			b	1.098	0.0070	156.1877	0.0001	

As a result of DBH analysis to use ground data and tree height estimated from LiDAR, accuracy of *Pinus koraiensis* was estimated at 0.73, *Larix leptolepis* 0.73 and *Quercus* spp. 0.86.

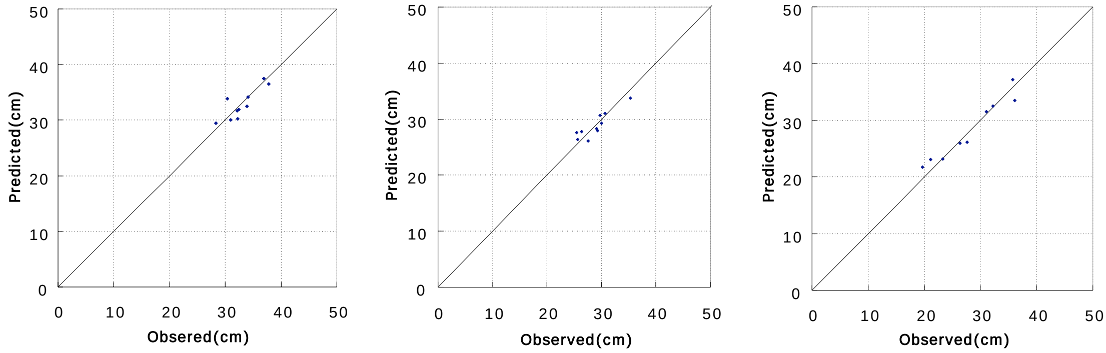


Pinus koraiensis *Larix leptolepis* *Quercus* spp.

Figure 5 . DBH Accuracy between observed and predicted

3. Estimation of Basal Area and evaluation of accuracy by tree species

As a result of validating Basal Area accuracy, total species is estimated at 0.66. By three species, *Pinus koraiensis* was estimated at 0.68, *Larix leptolepis* 0.66 and *Quercus* spp. 0.60.



Pinus koraiensis *Larix leptolepis* *Quercus* spp.

Figure 6. Accuracy analysis of Basal Area

4. Estimaton of stands volume and biomass by tree species

4.1. Classification of tree species using digital aerial photography

Accuracy of Classification was estimated significantly at 0.7688. After computing occupied area by species using classified imagery, stands volume and biomass were estimated by tree species.

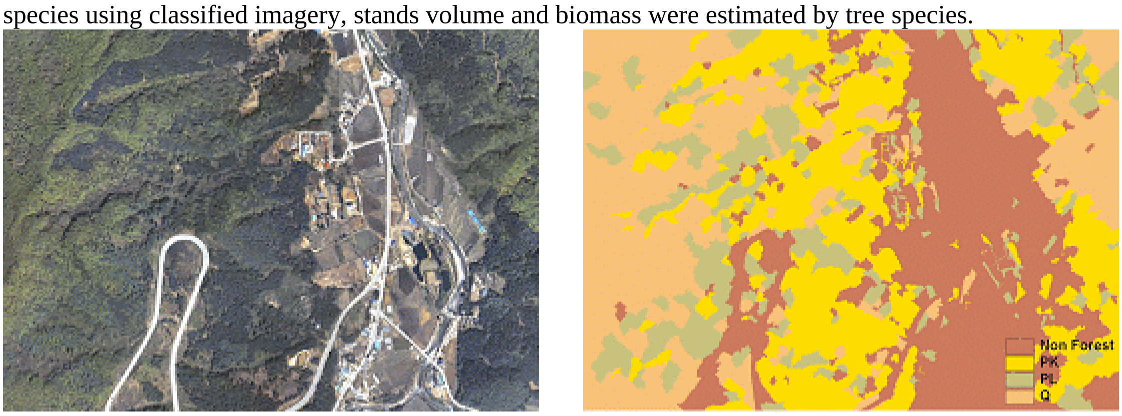


Figure 7. Segment Based classification of digital aerial photograph

Table 6. Error matrix of segment based classification

Classified Data	PK	PL	Q	Non Forest	Row Total	User's Accuracy
PK	8	1	1	0	10	0.8000
PL	3	7	0	0	10	0.7000
Q	0	0	9	1	10	0.9000
Non Forest	10	1	2	27	40	0.6750
Column Total	21	9	12	28	70	-
Producer's Accuracy	0.3810	0.7778	0.7500	0.9643	-	0.7688

4.2. Computation of stands volume and biomass

4.2.1. Estimation of canopy and stands volume

Stands volume were estimated by adding Clear-Length Height volume to canopy volume created using TIN about whole stands. Clear-Length Height volume were estimated by multiplying volume of single tree by the total number of trees.

Table 7. Stand volume by species

	Pinus koraiensis	***Larix leptolepis***	***Quercus* spp.**
Total Stand Volume(_)	2,016,595	1,159,133	2,925,199
Stand Volume(_/ha)	61,070	111,884	79,610

4.2.2. Estimation of biomass

Sigle tree and Stands biomass were calculated by the equation using and single tree and stands volume. A a result, single tree volume of *Pinus koraiensis* was estimated at 376kg, *Larix leptolepis* 422kg and *Quercus* spp. 409kg. Additionally, stands volume of *Pinus koraiensis* was proved to 1,330,953tdm, *Larix leptolepis* 975,410tdm and *Quercus* spp. 3,471,627tdm.

Table 8. Biomass using single tree and stands

	Pinus koraiensis	***Larix leptolepis***	***Quercus* spp.**
Single Tree	376kg	422kg	409kg
Stand	1,330,953tdm	975,410tdm	3,471,627tdm
tdm/ha	40,306	94,150	94,481

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