ESTIMATION OF STAND HEIGHT AND FOREST VOLUME USING HIGH RESOLUTION STEREO PHOTOGRAPHY AND FOREST TYPE MAP

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ABSTRACT:

Traditional field methods for measuring tree heights are often too costly and time consuming. An alternative remote sensing approach is to measure tree heights from digital stereo photographs which is more practical for forest managers and less expensive than LiDAR or synthetic aperture radar. This work proposes an estimation of stand height and forest volume(m^3/ha) using normalized digital surface model(nDSM) from high resolution stereo photography(25cm resolution) and forest type map. The study area was located in Mt. Maehwa model forest in Hong Chun-Gun, South Korea. The forest type map has four attributes such as major species, age class, DBH class and crown density class by stand. Overlapping aerial photos were taken in September 2013 and digital surface model(DSM) was created by photogrammetric methods(aerial triangulation, digital image matching). Then, digital terrain model (DTM) was created by filtering DSM and subtracted DTM from DSM pixel by pixel, resulting in nDSM which represents object heights(buildings, trees, etc.). Two independent variables from nDSM were used to estimate forest stand volume: crown density(%) and stand height(m). First, crown density was calculated using canopy segmentation method considering live crown ratio. Next, stand height was produced by averaging individual tree heights in a stand using Esri's ArcGIS and the USDA Forest Service's FUSION software. Finally, stand volume was estimated and mapped using aerial photo stand volume equations by species which have two independent variables, crown density and stand height. South Korea has a historical imagery archive which can show forest change in 40 years of successful forest rehabilitation. For a future study, forest volume change map(1970s~present) will be produced using this stand volume estimation method and a historical imagery archive.

1. INTRODUCTION

Traditional field methods for measuring tree heights are often too costly and time consuming. An alternative remote sensing approach is to measure tree heights from digital stereo photographs which are more practical for forest managers and less expensive than LiDAR or synthetic aperture radar.

St-Onge and Achaichia (2001) revealed that using traditional methods of field survey or aerial photograph interpretation to gain information on exact forest area and stand volume is not feasible for large programs because of costs and time constraints.

Recently, there has been increasing interest in the advanced processing of high spatial resolution digital airborne imagery to generate image-based point clouds, from which vertical information with similarities to ALS can be produced (White et al., 2013).

This work proposes an estimation method of stand height and forest volume (m^3/ha) using image-based point clouds from high resolution stereo photography (25cm resolution) and forest type map.

2. MATERAL AND METHODS

2.1 Study area

The study area is Maehwa Model Forest (MMF), located in in Hong Chun-Gun, South Korea (Figure 1). MMF covers 6,953 ha and it consists of 54% of natural forests and 46% of artificial forests. The study area contains various sizes of trees, shrubs, and grasses. The dominant tree species in the study area include *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis and Quercus spp.*

Figure 1. The location of study area

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2.2 Digital aerial data and forest type map

A DMC 01–125 camera with a 120 mm lens was used to acquire high-resolution images (Table 1). The forest type map was also used which has four attributes such as major species, age class, DBH class and crown density class by stand (Figure 2). Attributes of forest type map is decided based on crown area of dominant tree which consists of upper story.

Table 1.Details of the digital aerial data used in this study

Acquisition date	2013.9.30
Area	25 ㎢
Bands	RGB
GSD	25cm

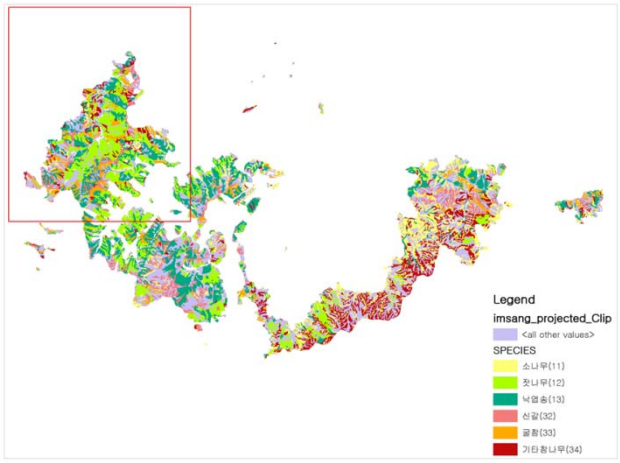

Figure 2.Forest type map

2.3 Ground data

32 ground circular sample plots which have radius of 11.3m were allocated at study area considering species and DBH class with forest type map. Then, height, DBH, species and location of individual trees were collected (Table 2, Figure 3). The location of individual tree was calculated using distance and azimuth from center coordinates of sample plot with DGPS. Tree heights were measured using Haglof Vertex and TruPulse.

Table 2.Details of field survey

date	1st (2014.4.29.~5.1) 2nd (2014.5.19.~5.23)
Number of plots	32
Number of trees	577
Type of sample plot	circular(radius=11.3m)
inventory	Location of individual tree(distance, azimuth) species, DBH, height

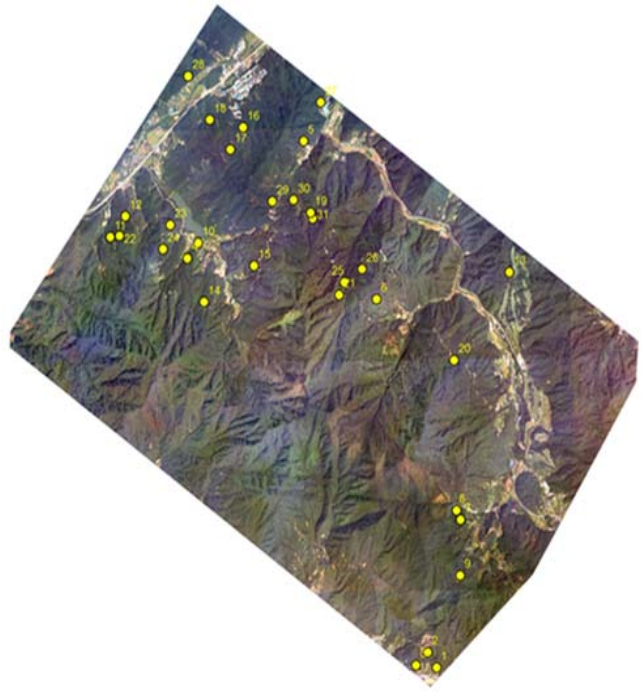

Figure 3.Location of sample plots(N=32)

2.4 Methods

2.4.1 Extraction of nDSM from stereo photography

Image-based point clouds from stereo-image strips were used to calculate a Digital Surface Model (DSM) with a spatial resolution of 0.25 m x 0.25 m. Then, digital terrain model (DTM) was created by filtering DSM and subtracted DTM from DSM pixel by pixel, resulting in a normalized Digital Surface Model (nDSM) which represents object heights(buildings, trees, etc.).

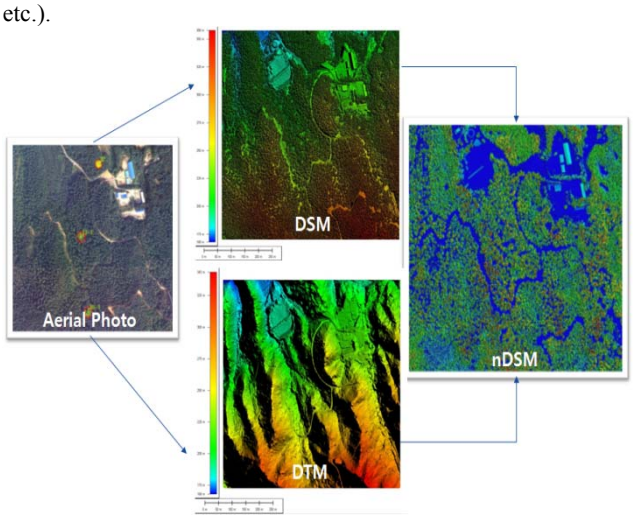

Figure 4. nDSM extraction from differencing between DSM and DTM of stereo aerial photos

2.4.2 RMSE

In order to assess individual tree heights derived from nDSM, first of all reference crowns were manually delineated with the visual interpretation of with overlapping ortho-photo and ground data which has tree height and X, Y coordinates. Then

individual tree heights from each crown were obtained using boundary of individual tree crown. Finally RMSE was calculated from the difference between the reference height and height derived from nDSM at plot level.

2.4.3 Mean stand height and crown density

Two independent variables from nDSM were used to estimate forest stand volume: crown density (%) and stand height (m).
First, crown density was generated by dividing crown area by stand area. For obtaining a crown area, crown delineation from nDSM was performed using watershed segmentation considering crown ratio. Crown ratio (i.e., live crown ratio or crown length ratio) was calculated as the ratio of crown length, which refers to the distance from a live crown top to a live crown base, to the tree height(Fang *et al*., 2016).
Next, mean stand height was produced by averaging individual tree heights in a stand. In order to get individual tree heights in all stands, top points of trees were derived from nDSM using FUSION S/W provided by U.S. forest service. Then mean stand height was calculated with each stand polygon of forest type map using zonal statistics in ArcGIS.

2.4.4 Stand volume

Finally, stand volume map was derived from an aerial photo stand volume equations by species which have stand height and crown density using map algebra (Table 3).

Table 3.Aerial stand volume equations

Species	Aerial volume equation	R^2	SE(%)
Pinus densiflora S. et Z.(Ganwon province)	lnV=-7.7049+1.7509lnH+1.8275lnCD	0.98	13.3
Quercus spp.	lnV=-7.5024+1.5828lnH+1.7481lnCD	0.96	18.9
Pinus densiflora(Central province)	lnV=-15.9515+1.1778lnH+4.0791lnCD	0.88	22.6
Pinus rigida	lnV=-10.1462+0.8763lnH+2.8639lnCD	0.87	15.4
Pinus koraiens S. et Z.	lnV=-6.3278+0.7801lnH+2.1076lnCD	0.81	15.3
Larix leptolepis	lnV=-8.2210+0.9359lnH+2.4305lnCD	0.74	17.9

(resource : KFRI research report 48. 1993)

3. RESULTS

To measure of the difference of the nDSM derived heights compared to the field observed heights, the root mean square error (RMSE) was calculated for 577 individual trees. RMSE results show from 0.63m to 2.65m for each trees and RMSE for average tree height of all plots reached 0.96 m (Figure 5).

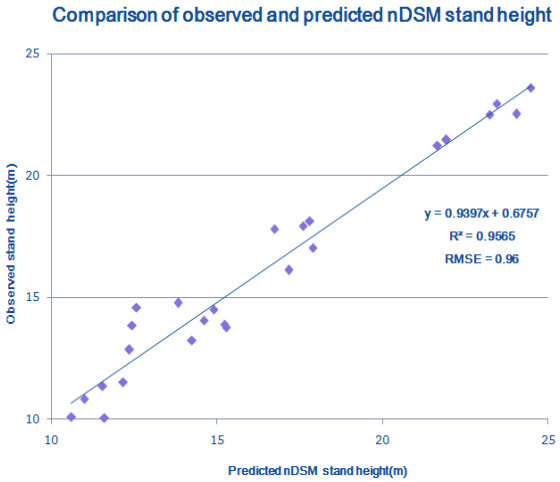

Figure 5.Comparison of observed and predicted nDSM stand height

nDSM derived tree heights were averaged by each stand polygon of forest type map resulting in mean stand height (Figure 6). Also, crown density was derived by crown delineation from nDSM considering crown ratio (Figure 7). These two attributes, stand height and crown density added to forest type map for new attributes.
Finally, substituting these two attributes for two variables in a aerial photo stand volume equation resulted in forest stand volume map (Figure 8).

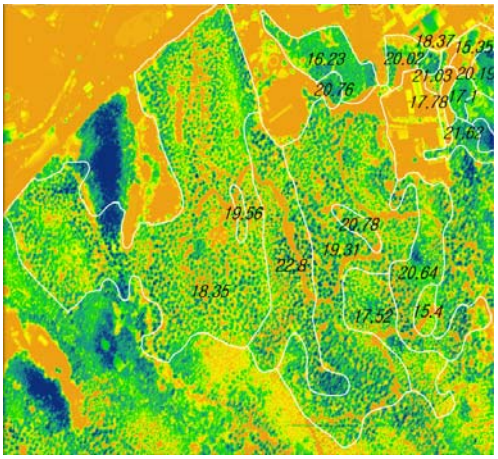

Figure 6.Stand height map

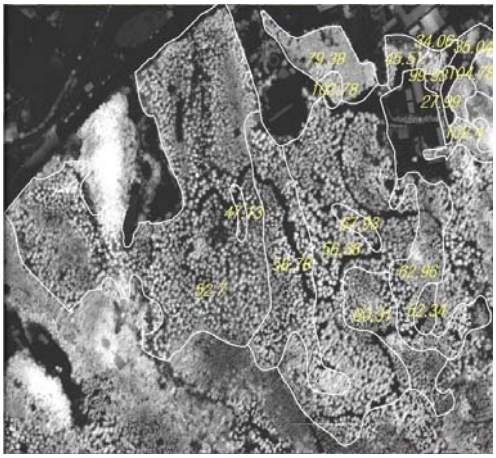

Figure 7.Crown density map

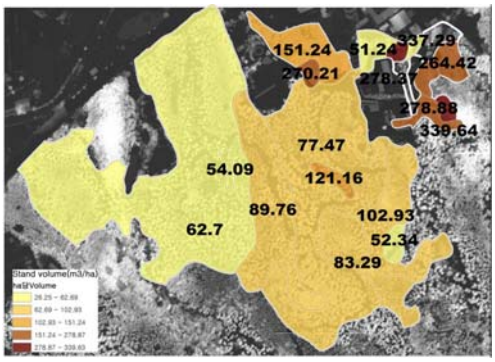

Figure 8.Stand volume map

4. DISCUSSION

This study shows that nDSM derived tree height is more effective estimation method compared to conventional photogrammetric measure considered in large area like country level. Especially, adding stand height and crown density to forest type map shows potential of forest stand volume estimation which is difficult to estimate by only existing forest type map.

South Korea has a historical aerial imagery archive which can show forest change in 40 years of successful forest rehabilitation. For a future study, forest volume change map (1970s~present) will be produced using this stand volume estimation method and a historical imagery archive.

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