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Estimation of forest above-ground biomass rate using airborne LiDAR data

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Abstract: The study provides an overview of contemporary approaches to assess forest above-ground biomass. A remote sensing method for assessing biomass using airborne LiDAR (Light Detection And Ranging) data is proposed by authors, since it has a verified technology that can be used to accurately assess above-ground forest biomass. The brief review of methods for detection of single tree using airborne LiDAR data is presented. We proposed and discussed a new tree-based approach for biomass assessment with the use of LiDAR data. Results of morphologic parameters calculations, conducted with the help of some automated methods are described. The results of experimental investigation confirm availability and correctness of the proposed method. The results of biomass calculation in FORKOME are presented. The proposed methodology was tested in forest areas in Poland. Perspectives for further research in order to improve the precision of method are outlined as well.

Key words: Airborne LiDAR data, biomass, DBH, FORKOME, single tree detection

Introduction

Biomass is one of the integrated biophysical parameters, which does not only enable to obtain a realistic assessment of the forest capacity and other vegetation within a specific area, but also plays a significant role in studies of carbon cycles in nature. Obviously, biomass is determined through the oven-dry mass of the above-ground portion of a group of trees in forestry (Avery, Burkhart 1994), and measuring the above-ground forest biomass in the natural conditions – which is considered to be quite a difficult task. The reason for this is the fact that the value of biomass depends on such tree components as trunk, branches and leaves, wherein the characteristics of these components should reflect the average composition of the forest.
All currently known methods for measuring above-ground forest biomass

are divided into two groups:
1) are based exclusively on data from field measurements of trees and their components (ground-based methods);
2) methods that use distance information derived from air or space (remote sensing methods).
Field measurements can be made by selecting a specific forest material, such as pollination of typical tree-representatives and subsequent evaluation of their characteristics (direct destructive path) or remote manner, therefore without the direct interference into the forest system and its elements. It should be noted that in both cases the problem is solved by means of drawing allometrical model, with tree trunk diameter at breast height (DBH) as its key parameter (Zhou, Hemstrom 2009).
In the last decade remote sensing methods has been greatly developed and improved (Lyalko et al. 2006), even if they do not provide, as field methods do, a highly accurate estimations of biomass, however, they have significant advantages in efficiency and allow for inspection of large areas, including ones that are hardly accessible.
All necessary measurements and observations in the remote sensing methods occur through processing and analyzing species data (images), which are received by using technical means established on air platform (airplane or helicopter) or on board of the spacecraft. Images that are required can be provided by photographical, digital multispectral, radar or LiDAR means. Each of the methods concerned has its advantages and disadvantages, that is why recently many studies has been conducted that have studied the effect of integration of specific tools. In particular, Nichol and Sarker (2011) proposed to estimate biomass based on integration of multispectral images of two satellite sensors – AVNIR-2 and SPOT-5 (10 m spatial precision). Lefsky et al. (2002) showed a perspective of biomass estimation with the use of LiDAR data, since it becomes possible to form a 3D-image and to identify every tree and LiDAR data provides highly detailed terrain. However, the method based on LiDAR data has, like other remote methods, limitations, most noticeable is the need for field measurements, observations and adapting the selected model to the properties of the study area.
In this paper, a method for estimating above-ground forest biomass using airborne LiDAR data was proposed, part of which is a single tree detection, what enables to calculate with a necessary accuracy and completeness morphological parameters of trees and thus determine the assessment of forest biomass.

Materials and Methods

Study area and input data

As a research area there were used some parts of the forest area of about 1 km^2 in Lublin, Eastern part of Poland (51°09’17”N 22°32’04”E) (fig. 1).

There were analyzed 8 compartments:
- No 05-27-1-12-268-i-00 composed by *Carpinus betulus* 24 years (1GB);
- No 05-27-1-12-276-c-00 composed by *Larix decidua* 49 years (2MD);
- No 05-27-1-12-276-a-00 composed by *Betula pendula* 69 years (3BRZ);
- No 05-27-1-12-281-a-00 composed by *Pinus sylvestris* 68 years (4SO);
- No 05-27-1-12-275-b-00 composed by *Pinus sylvestris* 71 years (5SO);
- No 05-27-1-12-282-b-00 composed by *Quercus robur* 131 years (6DB);
- No 05-27-1-12-268-h-00 composed by *Quercus robur* 102 years (7DB);
- No 05-27-1-12-269-a-00 composed by *Quercus robur* 53 years (8DB).

LiDAR data for the appointed area were received with the use of Optech ALTM LiDAR with the following characteristics: the working wavelength of 1,064 micrometers; height variety of about 10 cm; ground resolution of about 12 points per 1 m^2; opportunity to commit four separate pulses in range; dynamic range of the signal equals 12 bits.
In addition, the research process also involved data obtained by field measurements and observations of individual objects and areas on the territory of the study. Finally, there were used (in order to distinguish areas) forest maps provided by State Forest IT System.

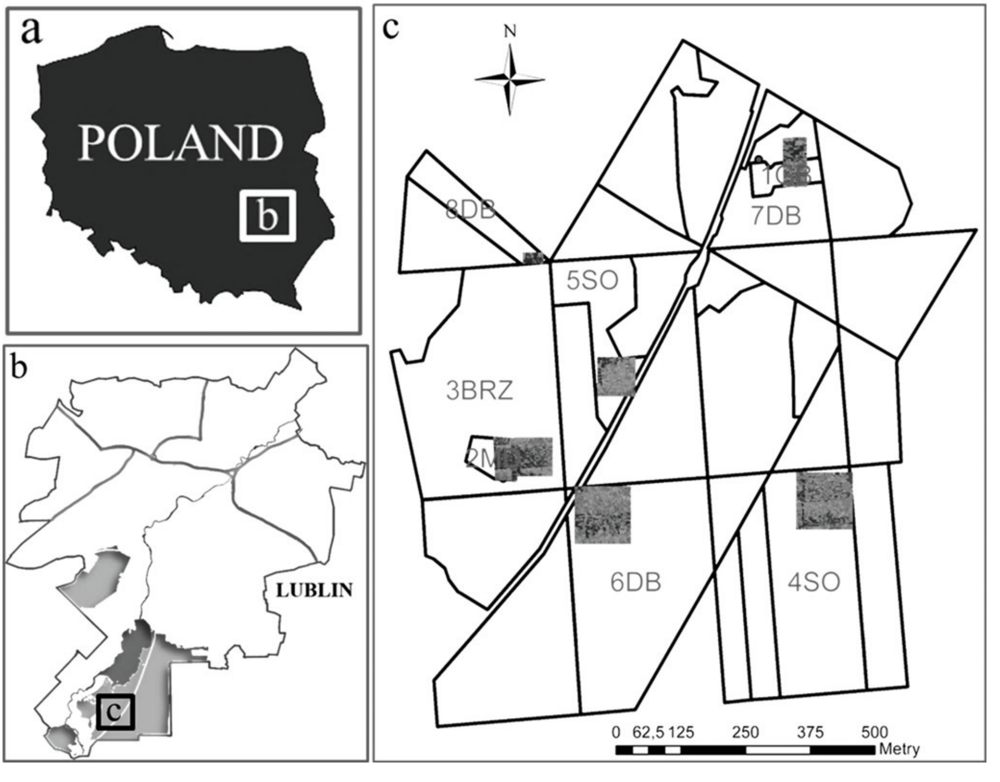


Fig. 1. Study area and test sites.

Data Evaluation: scheme and experimental results

Evaluation of above-ground biomass according to LiDAR data based on single tree detection methods implemented by the scheme is presented on figure 2. The most problematic issue was the selection of methods for accurate separation of trees from LiDAR point cloud, for which a range of modern methods and approaches was analyzed that are discussed below.

Analysis techniques for isolating trees according to LiDAR data

LiDAR data processing is possible in three spatial description of the object, meaning that information about each tree can be obtained in 2D or 2,5D-form, as well as in 3D (Semko 2014).

In 2D analysis, raster serves as an input material, the pixel importance of which can be of any attributive information from LiDAR data (intensity, slope, number of return, RGB values, etc.).

Processing of 2,5D is to obtain a digital surface model (DSM) of the point cloud. In this case, DSM is used in the same manner as the spectral brightness of the image, but takes precedence in the classification of shade gradation, therefore each pixel indicates the actual height, rather than the spectral brightness (Hyyppä, Inkinen 1999).

Using 3D-method is based on the analysis of the LiDAR data as a “point cloud” in three dimensions, that allows to obtain a three-dimensional figures of a tree, not just morphostructural values of plateau forest cover (Morsdorf et al. 2003).

In Semko (2014) there were three options considered for the spatial description of the object and some algorithms for automated selection of trees from LiDAR data, which are to be implemented more rapidly or easily when using GIS technology. According to Semko (2014) the best result of selecting trees in the forest can be obtained using the 2,5D method – about 76% of trees identified, 2D – about 55% of trees identified, 3D – about 54% of trees identified.

Therefore, for selecting and obtaining parameters of individual trees for estimating biomass of terrestrial LiDAR data, in this study there were used findings of local maximums and automated identification of watershed line in 2,5D.

Processing of LiDAR data

The LIDAR data processing was carried out using specialized software TerraScan of Finnish company Terrasolid. It begins with identification and filtering points within the soil (Gr). When performing this task, it turned out that in a simple way, the program can do TerraScan automatically, while in case of complex morphology, it was necessary to manually adjust certain parameters (increasing or reducing the distance of the interpolation points, the angle of incline, etc.).

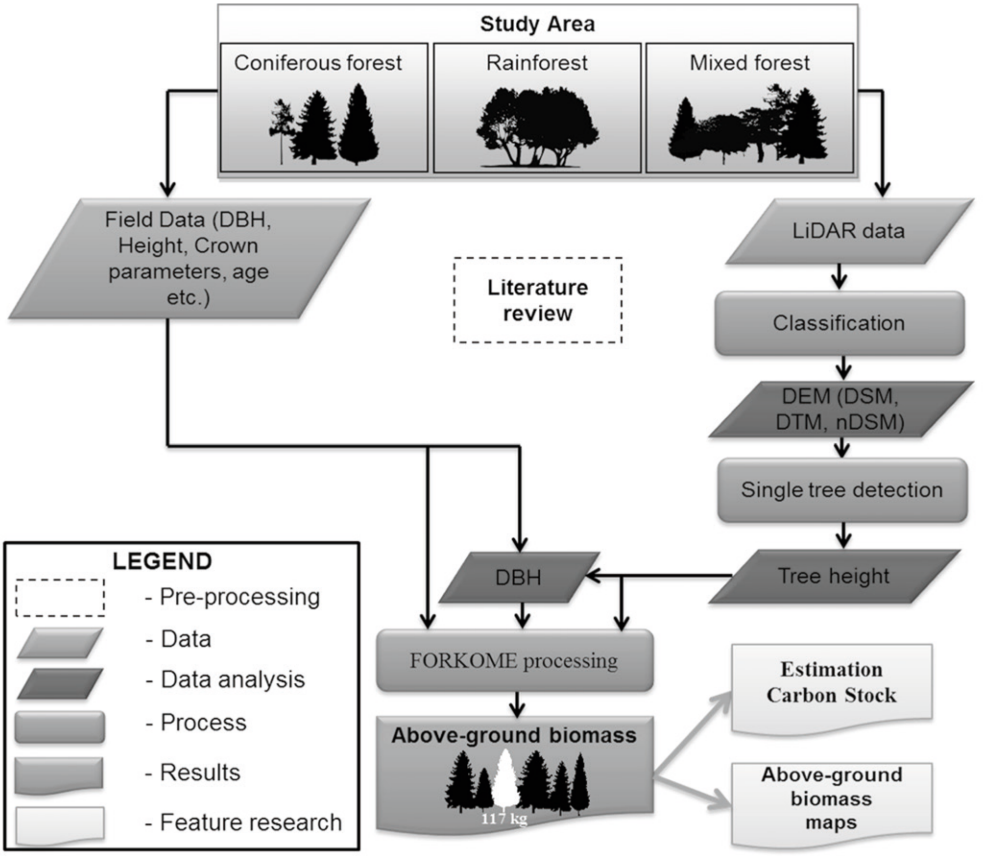


Fig. 2. Methodology scheme for above-ground biomass assessment using LiDAR.

The remaining points were divided into two groups, depending on the height of the location: situated above the ground up to the height of 1,37 m inclusively (this height was selected as a constant that is used in ground measurements for obtaining diameter at breast height (DBH), which is defined as 4,5 feet (1,37 m) above the forest floor) and those situated above the determined height.

As an input material taken from classified point cloud LiDAR data there were created bitmaps DSM and digital terrain model (DTM) at a resolution of 0.5 m height, with the highest value for each pixel for DSM and the mean value for DTM. This transformation of LiDAR data into raster form was conducted using the tool «Point to Raster», ArcGIS.

The next step was to identify local maxima that are further considered as the tree tops. Pixel is considered to be local maximum in case when the adjacent pixels have received below value or do not belong to the group of particular pixel. The points that are too close to each other were excluded on the basis of the criteria of minimum distance and nearest neighbor algorithm. The threshold distance may vary depending on the type and age of the forest. For instance, viewing the stand, which is dominated by old

trees, the threshold distance should be increased as the local maxima that are close to each other, are likely to represent only branches, and therefore should be eliminated. Thus, for young trees local maximum will be at the peak of the crown, and the distance between the points will be relatively higher. According to field measurements in this study, it was decided to use a threshold of 3,0 m for areas dominated by old trees and 1,0 m for the young (as stand density in areas with young trees is very high).
In order to determine tree height a normalized digital terrain model (nDSM) was calculated. This model is created by subtracting the height values DSM of the corresponding values DTM (Popov, Semko 2013). Normalization of DSM was conducted in order to remove the effects of the terrain and to obtain absolute height of each point above the ground. Difference in height between the point of local maximum and foundation point was considered as normalized height of the point, therefore absolute height. Thus, the local maxima with values less than 3 m were excluded, since they can be classified as forest bushes, therefore as algorithm error (Popov, Semko 2013).
The next step was the calculation of the diameter at breast, according to the formula (Kozak et al. 2005):

$$DBH = \frac{-B_2 + \sqrt{B_2^2 - 4 \cdot (-h \cdot 100 + BH) \cdot B_3}}{2 \cdot B_3}$$

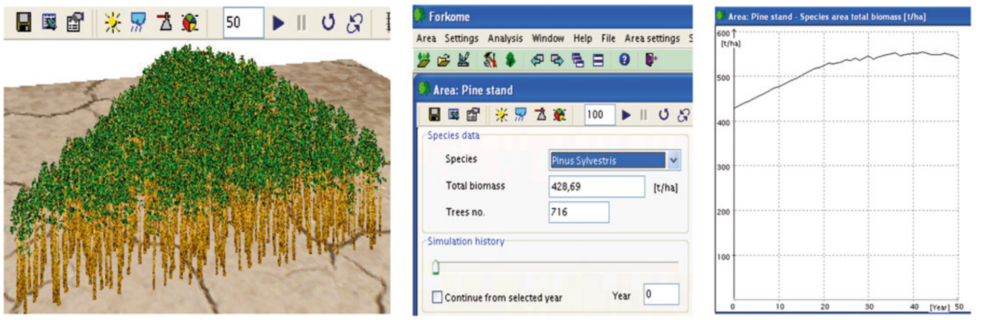
where:

$$B_2 = 2 \cdot \frac{h_{\max} - BH}{d_{\max}} \quad \Big| \quad B_3 = \frac{h_{\max} - BH}{d_{\max}^2}$$

BH – brest height (1,37m), *h* – the absolute height of the tree,
h_{max} – the maximum height for a tree species, d_{max} – maximum diameter of the crown.

Results

The final step was the calculation of biomass in FORKOME (Kozak et al. 2007, 2012) model on data collected from field measurements and ALS data. On figure 3 the result of tree biomass estimation is presented, which is 428.69 tons per 1 ha for separation 05-27-1-12-275 -b -00 with domination of Pine (*Pinus sylvestris* L.).
Moreover, in FORKOME model there was predicted the dynamics of total tree biomass (fig. 3c) for 50 years. Thus, according to the curve on the graph, there can be noticed a tendency of biomass growth up to 550 t / ha at 42nd year of the prognosis and a further decrease.



a b c

Fig. 3. The estimation of forest above-ground biomass in the FORKOME model: a) visualization of the pine tree stand on a fragment of 05-27-1-12-275 -b -00; b) the total biomass of the trees at the start of the forecast (year 0 – input); c) predicted changes in biomass of pine trees (author I. Kozak).

Discussion

In the article the approach to biomass estimation based on the use of LiDAR data was analyzed. It was confirmed that the separation of trees from LiDAR data makes it possible to calculate morphological parameters of trees and thus, determine the assessment of forest biomass. The method of tree separation and brief description of data processing was provided as well. Integration of LiDAR data and field measurements in the selected area of research enabled us, by using FORKOME model, to obtain more realistic estimations of biomass, as well as to forecast future biomass evolution at the research site.

However, it must be noted that the biomass calculations that were received require further clarification. This includes, among others, the improvement of the applied approaches, which is what the authors plan to focus on in their future research.

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