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# SINGLE TREE DETECTION BASED ON AIRBORNE LIDAR (ALS) DATA

# WYKRYWANIE POJEDYNCZYCH DRZEW NA PODSTAWIE DANYCH Z LOTNICZEGO SKANOWANIA LASEROWEGO (ALS)

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## Introduction

After constructing a laser (maser) in the 1960's (Baltsavias et al., 1999), this technology starts to develop very rapidly. The first operating LIDAR *(LIght Detection And Ranging)* system was created in 1993 in the USA. From the very beginning, forests were one of the most explored environments. The first papers describing LIDAR for the extraction of forest parameters came in the 1970's, with a partcular focus on this field in Russia and the USA.

By the 1990's a large number of systems had been developed, together with improved and specialized instruments. The first systems could only collect one signal, now systems were available that could collect two echos. At the beginning of the 21$^{st}$ Century, multiple signal collection is available, and full waveform data.

This very high performance technology gives foresters the ability to investigate forest structure in a detail which was not possible before.Thanks to LIDAR, single tree analysis has become possible with a very reliable level of accuracy (St-Onge et al., 2005; Wack et al., 2003; Yu et al., 2004). One of the most important forest parameters is an accurate methodology for single tree detection. Because the number of trees is essential information for stand volume calculation (Hyyppä et al., 2005), a large number of methods have been developed, and yet more are under investigation (Persson et al., 2006; Riano et al., 2004; Tiede et al., 2005; Wack et al., 2003; Wang et al., 2008; Weinacker et al., 2004). The size of a properly defined tree crown can be correlated with diameter at breast height (dbh) and is often used for accurate tree/stand height calculations (Hopkinson et al., 2004).

This paper is a summary of previous experience of single tree detection, especially methods based on Crown Height Models (CHM), as well as presentation of current developments in this field carried out at the Warsaw Faculty of Forestry, Warsaw University of Life Sciences (SGGW).

## Methods of single tree detection

Generally, we can divide the methods of single tree detection into two groups. The first group of methods uses digital models as a foundation of the analysis. The second group works just with raw LIDAR data. The main concepts of this groups of methods will be described below, with larger attention to the base algorithms of the digital models.

### Single tree detection based on raw LIDAR point clouds

There are a lot of questions which have to be answered before raw data can be used for the purpose of single tree detection.

Firstly point cloud density (Fig. 1). From an economic point of view, the density has to be as low as possible, because very dense LIDAR data costs a large amount of money to collect. However, if the data are not dense enough, it is impossible to connect group of points into single trees. So a balance between these two aspects is crucial for investigation accuracy.

Different LIDAR systems have different spatial patterns and parameters to be defined so that the result of the photogrammetric flight will meet our requirements. For forestry analysis, the size of the beam footprint should be small, so the penetration will be higher. Scan angle should not be higher than 10 degrees. The altitude of flight influences footprint size and should also be controlled.

Another very important aspect which has an impact on segmentation accuracy is the number of forest canopy layers and under-story vegetation density. If the structure of the forest is very complicated (dense) or there are a lot of different layers overlapping each other, the environment becomes unsuitable for single tree detection – especially for layers below the top crown stratum.

The methods described here for single tree detection are based on finding bulks, or groups of points which can be interpreted as a single crown (Persson et al., 2006; Wang et al., 2008) or stems (Reitberger et al., 2007). Generally the density of LIDAR data in all cases is very high, with up to 50 points per square meter (Persson et al., 2006). For single stems detection, the full waveform LIDAR system was used. This method is not normally used because of the volume of data it generates and the difficulties of processing such a volume of data. Nevertheless it is often used for biomass research or for volume calculation.

### Single tree detection based on digital surfaces models

The literature includes a lot of publications describing different methods of segmentation, based on Digital Surface Models (DSM), and normalized Digital Surface Models (nDSM), Crown Height Models (CHM) or other surface models. Because of the diversity of forest structure, different methods of forest management and climate dissimilarities, there is no universal method of single tree delineation. Almost every country has their own methods, suitable for particular forest conditions met in particular regions. In this study, three different methods of single tree detection will be presented, all of which are based on the Crown Height Model.

The main questions during those processes are: “What kind of filter should be used?” and “What size of filter window should be used”. To find an answer to these questions is critical for segmentation based on surface models. Some authors assume that larger trees should not have any neighbors in specified radius, but allow for fallen trees to be artificially detected.

### Local maximum algorithm

The local maximum algorithm extracts all points from an image that have a gray value larger than the gray value of all its neighbors (4/8 – depend on system used). The assumption is that a local maximum is a tree top. So during counting, local maximum pixels are definedto obtain a single trees number. The disadvantage is that we are not able to define the border and size of crown.

### Pouring algorithm

The pouring algorithm regards the input image as a “mountain range”. First, in the image the local maxima are extracted. These are expanded so long as there are chains of pixels in which the gray value becomes smaller. In this process 4 or 8 pixel neighborhoods can be used. The advantage of this method is segment (crown) definition.

### Watershed algorithm

This method is similar to that above. The algorithm segments an image based on the topology of the gray values. The first step is an inversion of pixel values. In the resulting image that which before was a valley (low pixel value) becomes a hill (255 “subtract” previous value (for 8 bit image)), and that which was hill becomes a valley. From these, mountain range watersheds and basins are extracted. Watersheds correspond to the bright ridges between dark basins. As with the pouring algorithm, it is possible to delineate the border and size of the crown.

## Study areas

The results presented below come from work on LIDAR data acquired for two arreas: Milicz forest district and Rogów Forest Experimental Station.

In both cases the TopoSys Falcon II LIDAR system was used. The LIDAR system characteristics are listed below (Table 1).

Single tree detection was performed by using the different methods, described above, which form the base for digital model analysis.

**Table 1.** Laser system parameters

| Sensor type | Pulsed fiber scanner |
|---|---|
| Wave length | 1560 nm |
| Pulse length | 5 nsec |
| Scan rate | 83 kHz |
| Scan with | 14.3° |
| Data recording | first (FE) and last (LE) pulse |
| Flight height | 700 m |
| Size of footprint | 0.7 cm |

# Results

The first investigation was to use a local maximum algorithm to find the number of trees. The idea was to make a double filtration of the image and then finding a local maximum after each step (Fig. 2). Depending upon height and species, different window size filters were applied. Because of the data density and model resolution (0.5 m), it was impossible to analyze stands younger that 40–50 years old. The overall accuracy of the method for 325 sample plots was 77%, with $R^2$=0.53. Reference data were acquired during field surveying, so the number of real trees was known (517). The number of automatically detected trees was 396.

Despite the very good accuracy in terms of the number of detected trees, there was a disadvantage through using a region growing algorithm for crown radius delineation: thecrown shape acquired by this method was unrealistic. If the aim is just to find out the number of trees, then this method is recommended.

The second investigation aim was to find the best resolution of the Crown Height Model for single tree segmentation (Stereńczak et al. 2008). Three different model resolutions were used 0.25 m, 0.5 m and 1 m respectively. Thirty four sample plots were analyzed, for which field data were acquired as a reference. We found no statistically significant difference between 0.25 m and 0.5 m raster resolution for single tree delineation. For 1 m raster resolution, there was a significant decrease in the number of detected trees. The advantage of this method was the delineation of single tree crown size, and subtract from the image of forest gaps (Fig. 3).

# Discussion

This paper is a very short overview of LIDAR technology and three different single tree detection methods. The purpose was to give some basic facts about commonly used methods and to show problems and disadvantages. The first trials in Poland (Będkowski, 2004; Stereńczak et al., 2008; Wężyk et al., 2008; Zawiła-Niedźwiecki et al., 2008) provide evidence of large requirements for single tree detection methods. This is shown to be possible for specially selected stratum of forest stands. For Polish forest structure we can presume that more than 50% of them can be analysed using one of the segmentation methods. The single tree method can be a base for extracting other forest parameters, such as stand height, volume and biomass assessment.

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***Streszczenie***

*Prezentowana praca jest w pewnym sensie krótkim podsumowaniem metod określania liczby drzew na jednostkę powierzchni oraz przedstawieniem doświadczeń pracowników Wydziału Leśnego Szkoły Głównej Gospodarstwa Wiejskiego w tym zakresie. W pierwszej kolejności w tekście prezentowane są głównie metody segmentacji oparte na wysokościowym modelu koron (WMK). Poza tym mowa jest o pierwszych algorytmach do detekcji pojedynczych drzew i pni drzew z wykorzystaniem surowych danych punktowych z lotniczego skanowania laserowego.*

*W drugiej części autor opisuje własne doświadczenia zdobyte w trakcie projektów wykonywanych w Nadleśnictwie Milicz i w Leśnym Zakładzie Doświadczalnym SGGW w Rogowie. Biorąc pod uwagę strukturę gatunkową oraz różnorodność przestrzenną drzewostanów Polski, można stwierdzić, że dla dużej ich części możliwe jest określanie liczby drzew automatycznie, z dokładnością ponad 75%.*

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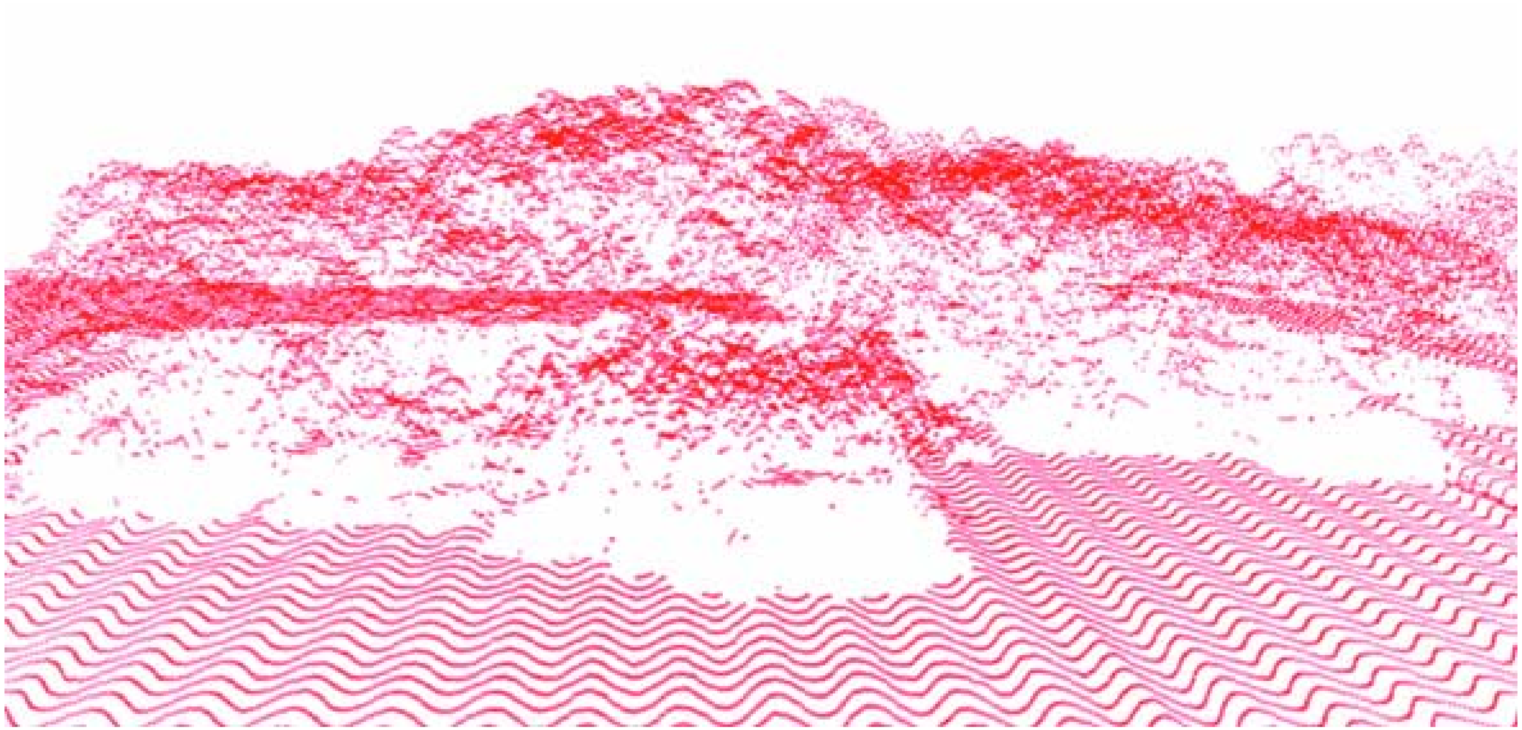

**Figure 1.** Raw LIDAR data point cloud

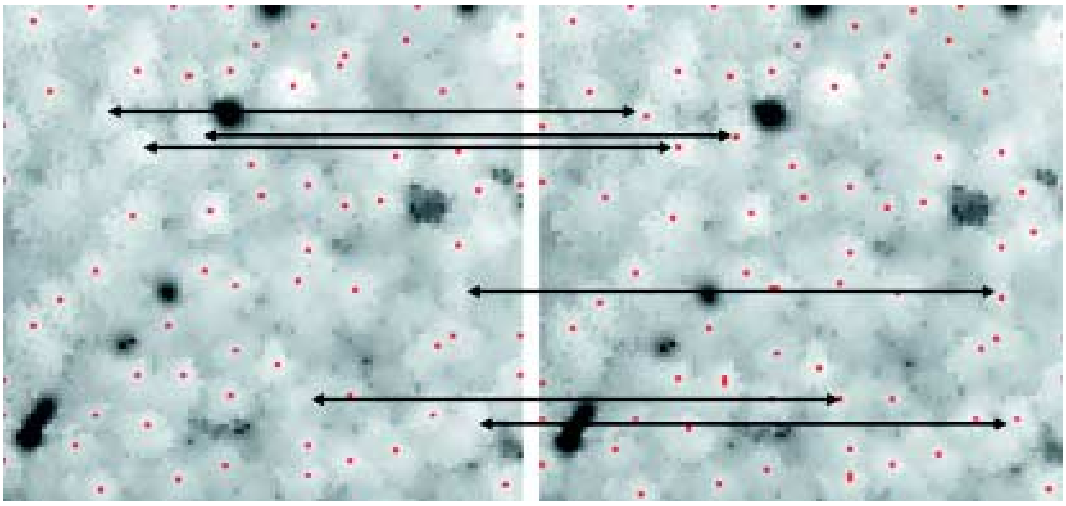

**Figure 2.** Comparison of extraction local maximum value on double filtered image. On the right side we can see more extracted tree tops after second filtration

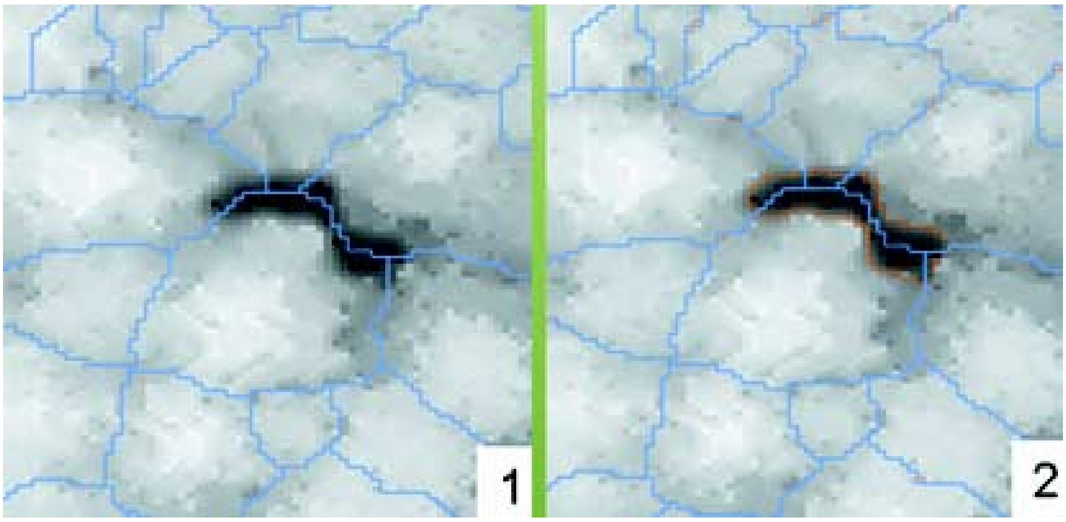


**Figure 3.** Defining real crown shape