FOREST PARAMETER ESTIMATION BY LIDAR DATA PROCESSING

Paula-Florina MURSA, Master Student – Military Technical Academy, paula.mursa@gmail.com

***Abstract**: An airborne optical remote-sensing technology, similar to RADAR, which can also be defined by another two words: laser and receiver system, LIDAR offers several advantages over the conventional methods of topographic data collection. Such high resolution gives higher accuracy for the measurement of the height of feature on the ground and above the ground. For this reason, LIDAR quickly sparked interest among the foresters and forest management received important answers regarding the single tree detection, parameters estimation, species type.Therefore it is desirable to automatically determinate the forest parameters. To make this aim realistic an algorithm has been developed to detect trees top and estimate their shape, an algorithm based on point cloud analysis. Detecting and separating trees provides useful information -parameters-, which can be used in many applications. From this reason, first was highlighted a new method based on math relations and ellipses construction. Secondly, were presented the results of the method on a study area and the observations regarding "unusual" cases, and the third aim was to evaluate this new method results with respect to the local maxima results.*
***Keywords:** LIDAR, forest parameter, image processing, single tree detection, algorithm,DSM, DTM, CHM.*

1. Introduction

LIDAR (Light Detection And Ranging) sensors work on the same principle as RADAR, firing a wavelength at an object and timing the delay in its return to the source to measure the distance between two points. Because laser light has a much shorter wavelength it is possible to accurately measure much smaller objects, such as aerosols and cloud particles, which makes it especially suitable for airborne terrain mapping.

When it is mounted on an airborne platform this device can rapidly measure distances between the sensor on the airborne platform and points on the ground to collect and generate densely spaced and highly accurate elevation data.

The principle of using laser for range measurement was known from late 1960s. At the same time it was thought of using the airborne laser for measurement of ground coordinates. However, this could not be realized till late 1980s as determination of location of airborne laser sensor, which is a primary requirement, was not possible. The operationalization of GPS solved this problem so the direct acquisition of a high density and accurate 3D point cloud has made LIDAR systems the preferred technology for the collection of topographic data to satisfy the needs of several applications. The geospatial user community became extremely interested in LIDAR data, not only for its capabilities to map the bare earth surface, but also for its promise for feature extraction (buildings and roads) or forest canopy characterization.

Now, there are over 200 LIDAR systems operating in the world. State-of-the-art systems are capable of 250,000 pulses per second, managing multiple pulses in the air at any given moment, capturing multiple returns from individual pulses, or even digitizing the entire return waveform. Data collection can be customized to meet specific application requirements, and end-users are supported by robust quality assurance methods and large data storage capacity.

LIDAR has revolutionized the acquisition of digital elevation data and has quickly become a de facto method of collecting height and surface information for a myriad of applications and analysis. There is no other method that can collect ground and surface height information as quickly, accurately and as cost-effectively.

These factors make LIDAR a highly viable option for all applications that require height, volume or 3D visualization information.

Basically, a LIDAR system consists of a laser ranging and scanning unit together with a Position and Orientation System (POS), which encompasses an integrated Global Navigation Satellite System (GNSS) and an Inertial Navigation System (INS). The laser ranging unit measures the distances from the sensor to the mapped surface while the onboard GNSS/INS component provides the position and orientation of the platform. The laser scanner measurements, the position and orientation information, and the mounting parameters are integrated in the LIDAR equation to provide the ground coordinates of the point cloud.

Concerning the strip adjustment the most important characteristics of LIDAR data are the irregular point distribution, the laser point accuracy, the impact of beam divergence, the return dependence on the physical characteristics of the surface and also the discrete return LIDAR, intensity, data formats are all important in LIDAR data processing.

2. Measuring forests with LIDAR

This technology allows the direct measurement of three-dimensional structures and the underlying terrain. Depending on the methodology used to capture the data, the resultant data can be very dense, for example, five points per meter. Such high resolution gives higher accuracy for the measurement of the height of features on the ground and above the ground. The ability to capture the height at such high resolution is LIDAR's principal advantage over conventional optical instruments, such as digital cameras, for elevation model creation.

In forestry, LIDAR can be used to measure the three-dimensional structure of a forest stand and produce a model of the underlying terrain. The structure of the forest will typically generate a first return from the uppermost limit of the canopy, followed by less intense returns through the canopy, down to the underlying terrain. Returns are classified into ground and aboveground sources. The ground returns can generate a detailed terrain of the area of interest, while the canopy returns can be filtered to provide forest structure at the canopy and middle level of the forest.

General speaking, there are individual tree attributes and stand attributes. Concerning the individual attributes (height, diameters at different heights along the stem and crown diameter) they are traditionally measured in the field but the method used in obtaining these measurements depends by the accuracy required. The stand attributes are refering to the mean of the volume (total volume) or dominant height.

LIDAR systems of different types have had success in recovering forest structure characteristics for a variety of vegetation types in a comparatively simple and direct manner. Because of its ability to measure canopy structure both horizontally and vertically, LIDAR has potential for providing the type of forest structure for estimation and modelling.

The main purpose of this section is to characterize forest stands. Regarding this, two main approaches can be used: one concerning *single tree* and another one *area-based*.

A lot of studies were made in both approaches. In general the approach *"single tree"* is to reconstruct the envelope of the canopy from the point cloud and detecting their peaks through the trees. The approach *"area-based"* consists on establishing the relations between the local statistics of the cloud point (quantize height, density) and forest stand variables (dominant height, basal area, volume).

For the first one, a detection algorithm for trees was developed under the Matlab environment [Clough et al., 2009]. First the DEM is calculated from the laser points classified as "ground". Digital Surface Model (DSM), which represents the upper envelope of forest cover, is calculated by taking into account the points classified as "above-ground" the highest on a given neighborhood. Filtering is applied to the image of the MNS to fill the pixels for which information is missing or aberrant (measurement noise) and to smooth the contours of the crowns (removal of artifacts associated with uneven branches and foliage). Finally a search of local maxima by sliding window used to select the possible positions of tree tops. The height of a tree is estimated as the difference between the height of a peak and that of the DEM point located vertically. The estimation of other characteristics (diameter, volume) requires a priori knowledge of allometric functions appropriate to stand between the heights of a tree at these other parameters. This method works well for stands where each crown is easily individualized and has a dominant peak.It also requires laser data with high density (> 5 points.m-2).

This method allows mapping the trees and estimating their individual characteristics. After importing this information into a Geographic Information System (GIS) it is possible to calculate the parameters of the stand (basal area and volume per hectare and dominant height) for predetermined zones or in a regular mesh in order to obtain more concise information on the scale of a clump.

The second approach, area-based supposes field measurements to be made in order to calibrate the multiple regressions between stand parameters and local statistics of the laser data (variables related to the local distribution of the height of the points).

These relationships are then used to estimate the value of variables stand on predetermined areas or as a mesh whose size must be of the same order of magnitude or greater than that of the plots used for calibration.

As a matter of fact, data processing of airborne laser scanner makes it possible to produce a quantitative mapping of forest variables where statistical inventories and mapping photogrammetry brought only a qualitative and quantitative data not located.

To conclude is important to emphasize that these parameters find their place in each part of forestry domain and the aim will be to have a tool to take advantage of their applications.

3. Data filtering, segmentation and tree detection using LIDAR data

In literature, some complete processing chains have been developed, starting with raw data as input and ending up with derived tree parameters for each single tree. Because raw data, a cloud of points, give a three-dimensional information of the structure of forest cover this is becoming a promising technique for modeling the forest's canopy and thus for completing several inventory tasks.

Extracting the ground from airborne laser scanning data has involved a lot of problems that are not entirely solved. Many algorithms have been presented in literature in order to overcome these problems, algorithms which use as input data point clouds and also algorithms which use raster range image. As I mentioned above, in this part I will present general aspects of the data processing components and also applications on a study area.

First of all, it is necessary to introduce digital terrain models. A *digital terrain model (DTM)* is a continuous function that maps from 2D planimetric position to terrain elevation z=f(x,y). This function is stored digitally, together with a method on how to evaluate it from the geometrical and possibly explicitly stored topological entities. In other words DTM is computed by **bilinear interpolation** of laser points classified as ground points over a regularly spaced grid of a resolution, res. The concept refers to the so-called 2.5D approach, where for one ground position (*x*,*y*) only one height (*z*) may be expressed.

The DTM is one special surface that can be reconstructed from laser scanning. It is, however, not only one. *DSM (digital surface model*) and *CHM (crown height model)* are other surfaces, not necessarily thoroughly physically defined. The DSM represents the top surface that is visible from above. It is equivalent to the DTM in open areas and runs on top of the vegetation canopies in forested areas. DSM is based on the highest point recoded in each pixel. The canopy height model can then be calculated by subtracting the DTM from the DSM.

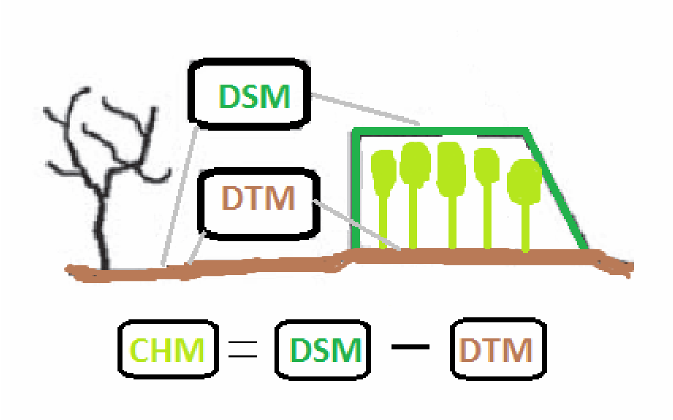


Fig.1. Digital Terrain Model, Digital Surface Model and Crown Height Model

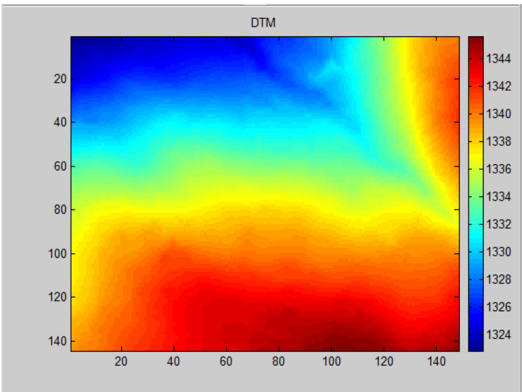


Fig.2. DTM

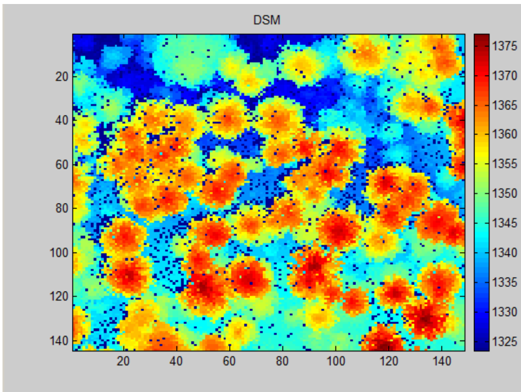


Fig.3. DSM

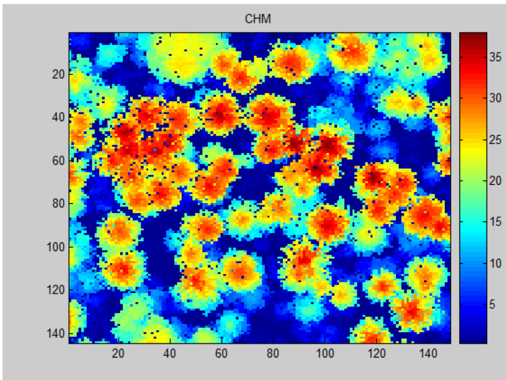


Fig.4. CHM

At this stage, after calculation of the raster images from the point cloud, we have the image very noisy, some pixels with a lower value than its neighbors. The scanning pattern usually leads to several low or void pixels in the surface models, due to the irregular sampling and to the shading effect of trees at the borders of flight strips. Concerning this and also the fact that there can be local irregularities of branches and more generally of the canopy, the image processing plays an important role.

The irregular sampling and shading effect of trees can be seen as a salt-and-pepper noise and be treated by several *non-linear* and *morphological filters*: median, adaptive median, closing, closing by reconstruction.

The irregularities of branches, of the canopy can be considered as high frequency noise and filtered by *Gaussian smoothing*.

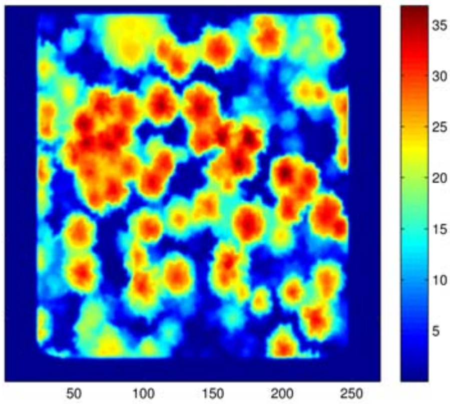


Fig.5. Gaussian smoothing

In general the **watershed segmentation** is a region growing algorithm that divides a gray–scale image on the influence zones of its local minima. The watershed segmentation is better understood if an analogy between the gray-scale image and a topographic surface is made. In this analogy, the point gray-level defines its topographic altitude. If a drop falls into the topographic surface, it will ideally run until it will reach a local minimum. Each local minimum *m* defines an influence zone as the set of points where a drop falling on them would reach *m.* continuing with the topographic analogy, each of these influence zones defines a catchment basin and the lines that separate two different basins are called the watershed lines.

Finally, to obtain a good segmentation with this algorithm it is necessary to transform the input image because the edges of objects appear like watershed lines. In our case, having the image with trees height it is enough to take as input the CHM to have an image where each tree is a watershed basin. The watershed lines represent the limits between trees.

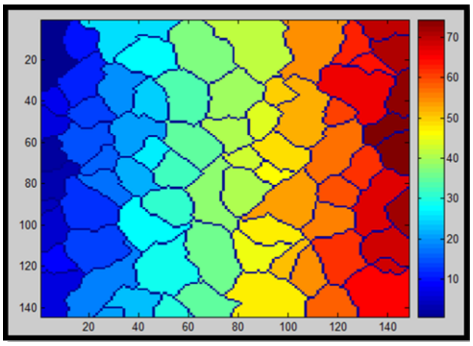


Fig.6. Segmented image

4. Applications in tree detection and forest parameters

Field data

The study area is located in the Chablais valley, in France Alps where seven 0.25 ha plots were established in March and July 2010. Laser data was acquired with a fullwave RIEGL LMS-Q560 scanner.


Fig.7. Field data

The algorithm

Airborne LIDAR (light detection and ranging) is becoming a promising technique for modeling the forest's canopy and thus for completing several inventory tasks. Parameters, such as tree height, timber volume and others related to the structure and distribution of the tree layer are usually needed. According with this, since around 1995, a large number of scientific studies have indicated a huge potential of airborne laser scanning data to provide highly accurate estimates of important parameters of forests.

Different methods for single tree detection have been developed relying on the two main approaches for using ALS to characterize forest resources: first, an area-based approach typically providing data at stand level and second a single-tree approach where individual trees are the basic unit for the assessment.

The purpose of this study is to solve the main problems with local maxima filtering, cases when small trees located close or under bigger trees are not detected or trees with tree top very close one to another may not be separated and also cases when some wrong treetops may be detected because of big branches. All these problems will be threated based on an algorithm for detecting and separating trees. The key point in algorithm steps is to *construct ellipses*, from here are starting all the observations and case studies which are emphasized during this chapter.

The algorithm consists out of three main parts. The first part studies the whole points cloud in the segment even if there are more trees, detecting the highest point and defining the levels, the second part treats individual each tree detected and in the last part there are constructed ellipses in order to separate the trees and define their shape.

The principle is quiet simple based on math relations, ellipses construction but its importance is clearly highlighted by results. The purpose is to detect trees which had not been detected after watershed segmentation, maxima extraction and selection, to define the shape of the tree in order to estimate parameters and also to separate them.

The objectives are contained in the entire contents of this chapter, starting from the detection trees, continuing with the separation, defining their form and in the end performing an exploratory evaluation of the algorithm parameters and a statistical study of the results.

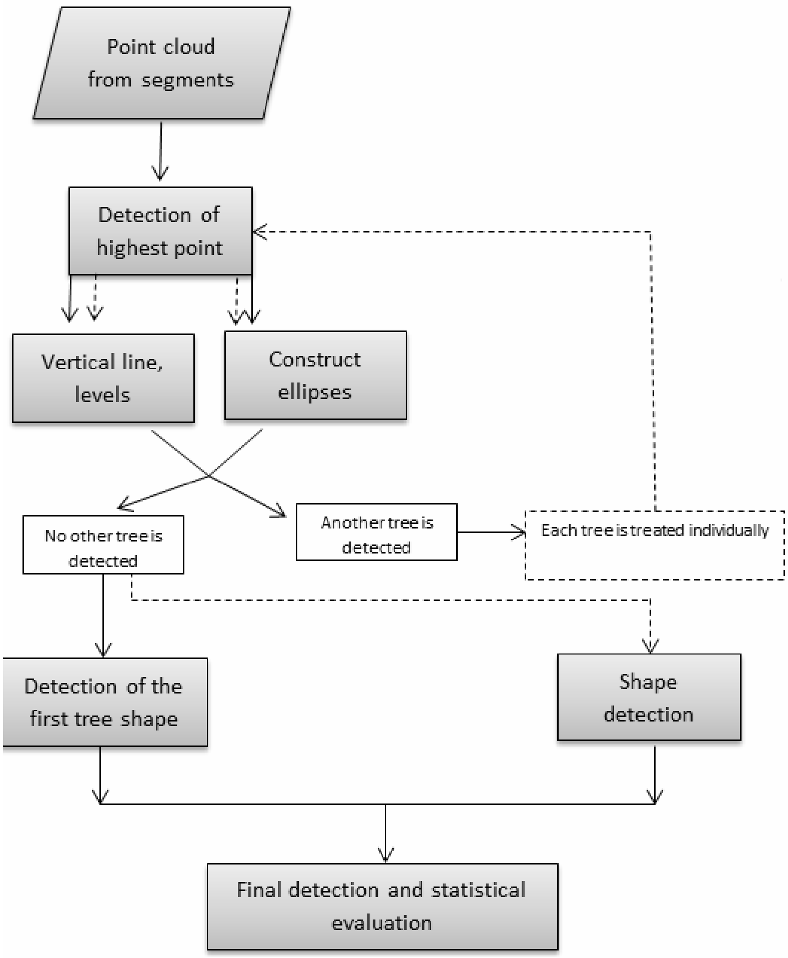
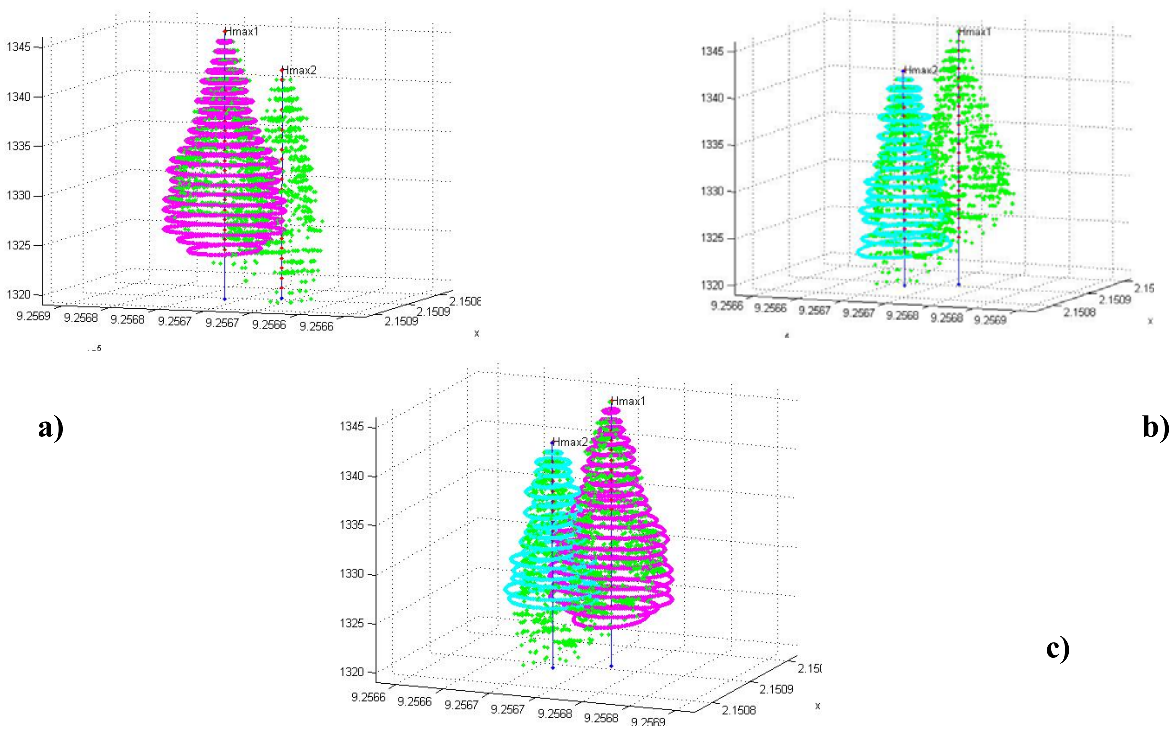


Fig.8. Algorithm steps

Fig.9 a,b,c Results



a)

b)

c)

For the study area, with this algorithm were correctly detected 35 trees from 82 inventoried trees, a percentage 42.68% with a 3% false positive.

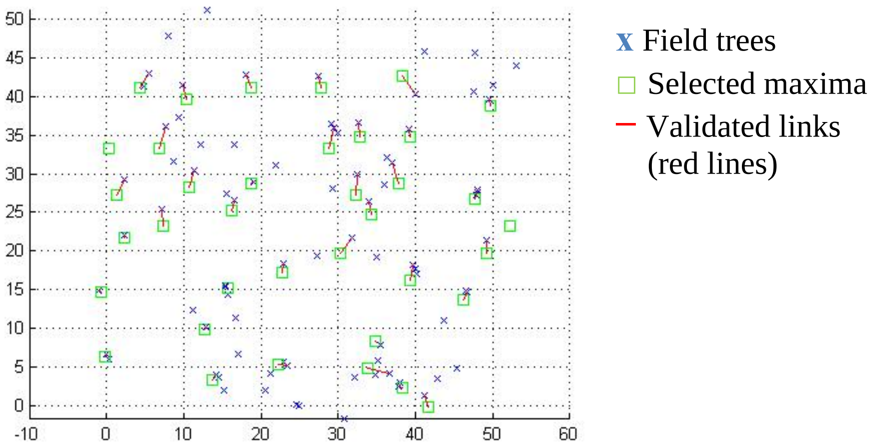


Fig.10 . Local maxima-matching results

The interest was moved on detecting small trees and tree with tree top very close one to another, because the big trees can be easily detected on a segmented image with local maxima. As it can be seen in the table..

With the proposed algorithm, constructing ellipses, all the big trees are detected and also 5 small trees.

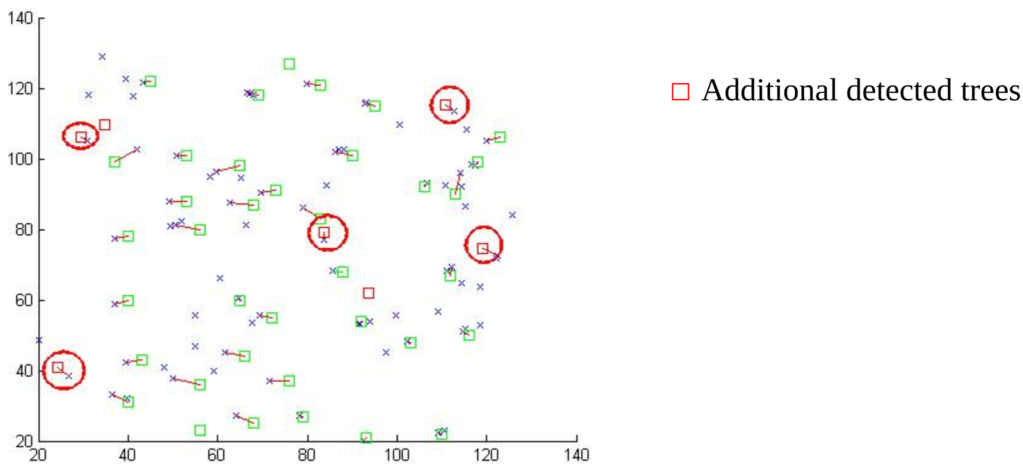


Fig.11 Local maxima and ellipses construction -matching results

Height (m)	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**Total**
Detected trees (local maxima)	0	0	2	0	0	**5**	**16**	**12**	**35**
Detected trees (construct ellipses)	0	**2**	**4**	0	0	**6**	**16**	**12**	**40**
Inventoried trees	0	22	12	3	6	9	17	13	82

5. Conclusions

When we say “LIDAR” we say complexity, accuracy, trustworthy source of high resolution elevation data, ability to perform temporal analysis, the development of advanced automated feature extraction, capabilities in mapping and the list can continue because even if we speak from military or civil perspective, the LIDAR world is seen through the lens of the end-users.

In forestry, LIDAR can be used to measure the three-dimensional structure of a forest stand and produce a model of the underlying terrain, things that make possible single tree determination and forest parameters calculation and estimation. An important aspect is that LIDAR overcome all traditional forest inventory methods by giving directly a wide range of information: digital elevation and surface models, tree heights, crown cover, forest structure, crown canopy profile. Post-processing of LIDAR data can reveal: canopy geometric volume, biomass, crown dimensions, density.

As a matter of fact, the above informations represent forest parameters which can be directly measured or calculated from direct mesurements and which are the focus for the entire study. In order to reach this level, to estimate the forest parameters, it is important to detect and separate all the trees from a study area. Definetely, it is important to eliminate all the artefacts considered as noise from the image, which can be defined by irregular sampling and shading effect of trees and by the irregularities of branches.

Different methods for single tree detection have been developed, regarding this, it was proposed an algorithm for detection, separation and forest parameter estimation based on math relations and ellipses contruction.

After running the algorithm, I was obtained a percentage 48.78% of detected trees with 4% of false positives and 68.28% of number of trees.

The main problems regarding the trees detection, separation and also about detection of their shape were solved with the proposed algorithm but the cases when the second tree is very closed to the first one are difficult to solve, that is a perspective of my study, to solve and discuss this cases.

LIDAR is becoming a promising technique for modeling the forest’s canopy and thus for completing several inventory tasks. Parameters, such as tree height, timber volume and others related to the structure and distribution of the tree layer are usually the base of all the applications.

6. References

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