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Vegetation structure determination using LIDAR data and the forest growth parameters

M Rybansky¹, M Brenova¹, J Cermak², J van Genderen³ and Å Sivertun⁴

¹University of Defence in Brno, Kounicova 65, 612 00 BRNO, Czech Republic,

²Mendel university Brno, Czech Republic,

³University of Twente, Netherlands,

⁴Swedish Defence University, Stockholm

Email: marian.rybansky@unob.cz

Abstract. The goal of this paper is to identify the main vegetation factors in the terrain, which are important for the analysis of forest structure. Such an analysis is important for forestry, rescue operations management during crises situations and disasters such as fires, storms, earthquakes and military analysis (transportation, cover, concealment, etc.). For the forest structure determination, both LIDAR and the forest growth prediction analysis were used. As main results, the vegetation height, tree spacing and stem diameters were determined

1. Introduction

The digital terrain model (DTM) represents the bare ground of the earth's surface without any objects such as plants and buildings. In contrast to a DTM, a Digital surface model (DSM) represents the earth's surface including all objects on it. The DTM does not change as frequently as does the DSM. The most important changes of the DSM are in forested areas due to the vegetation growth. Using LIDAR technology, see also [1-8] the canopy height model (CHM) is obtained by subtracting the DTM and the corresponding DSM. The crown DSM is calculated from the first pulse echo and DTM from the last pulse echo data. The main problem of the DSM and CHM data is the date of the airborne laser scanning.

This paper describes a method for calculating the forest structure changes using LIDAR data and the forest growth analysis results. The three main parameters are the mean height of vegetation, mean tree distances and thickness of mean tree trunk predicted using the relations between the canopy age and these parameters. The LIDAR DSM data (as a sample model) with an average density of 1 point per square meter was used to compare both data sources (vegetation growth curves values and laser data). The statistical calculations show that the tree growth curves increase relatively quickly from the beginning (young canopy), but becomes flattens out at the higher age.

That method was tested on a typical spruce forest stand. This spruce forest was chosen because it is the most common tree species in many countries located in central and northern Europe. The results of this experiment show that this method is fully applicable for the DSM generated from LIDAR data. The method can be appropriately implemented as a relatively cheap up-dating tool in the GIS technology between two laser scanning campaigns of a territory. This method can also be refined using the growth curves of individual types of trees.



2. Canopy structure prediction methods

Vegetation growth used to be characterized by a description of the state and characteristic of changes resulting from growth over time. As the definition of word “growing” we can imagine the quantitative enlarging of volume of biomass of living organisms. The descriptions of state and characteristic changes coming up during forest vegetation development are made by use of enumeration survey values. Basic values of enumeration survey are e.g. number of trees per square unit (this is a basic value for computation of mean spacing), mean thickness, mean height, circular base, stock, growth figure etc.

2.1 Number of trees per square unit

Number of trees per square unit $N \cdot \text{ha}^{-1}$ as a rule, tends to be regarded as value which is variable to a great extent. Generally, we can say that the development of this enumeration survey value depends on natural mortality and manmade operations. Basic factors which always affect this value are as follows:

- Age of vegetation.
- Woody plant species.
- Habitat.
- Technique of vegetation setup.

The number of trees per square unit is usually presented in relation to the age of the vegetation. We know that, with increasing age, the number of trees diminishes very quickly in the beginning, and later diminishes at a slower rate. We can express this fact by a simple analytic relation [9] and [10]:

$$N = \frac{B}{t^m} \quad (1)$$

where B and m are constants, t is an age.

The development of tree numbers depends also on woody plant species and habitat (see Fig. 1), more detailed see e.g. [9, 10, 11]. The spruce as the predominant tree type (in Central Europe) was selected.

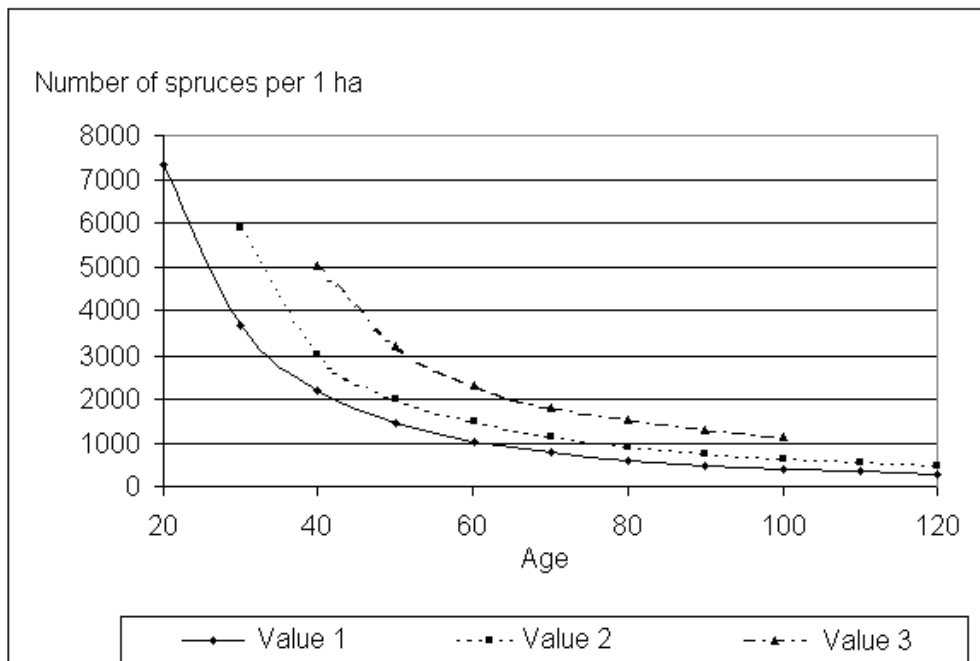


Figure 1. Number of spruce tree per ha in dependence on the age of the vegetation
 Values 1, 2 and 3 refer to the quality of the soil type.

The number of trees of the predominant species decreases rapidly in the period of youth, especially on fast-growing trees and light-demanding species and has considerably lesser value than on shade-loving woody plant species. At the same time, we have to remark that the growth of woody plants on fertile soils is more intensive. That is why the less fertile habitat has more trees than the rich fertile soil habitat at the same comparable age. Naturally, growing vegetation has in the early stage of development significantly greater number of trees per square unit than vegetation founded by plantation.

The development of tree number per square unit is presentable also by use of the other values. As an example, the relation of the evolution of tree numbers depends on:

- Mean tree spacing (MTS).
- Thickness of mean trunk.
- Mean height of growth.

The relations among the development of number of trees per square unit, thickness of mean trunk and mean tree spacing are considered as the closest one.

2.2 Mean tree spacing

The function of mean tree spacing is definable by number of trees for square spacing lay-out [9, 10]:

$$MTS \sim \sqrt{\frac{40,000}{\pi \cdot N}}, \quad \text{then} \quad N \sim \frac{40,000}{\pi \cdot MTS^2} \quad (2)$$

where N – number of trees per ha.

The number of trees as the function of tree spacing a_3 among the three adjoining trees (see Fig. 2) is computable by mathematic calculation. Variation coefficients for a_3 take values which are usable to computation of necessary number of measuring.

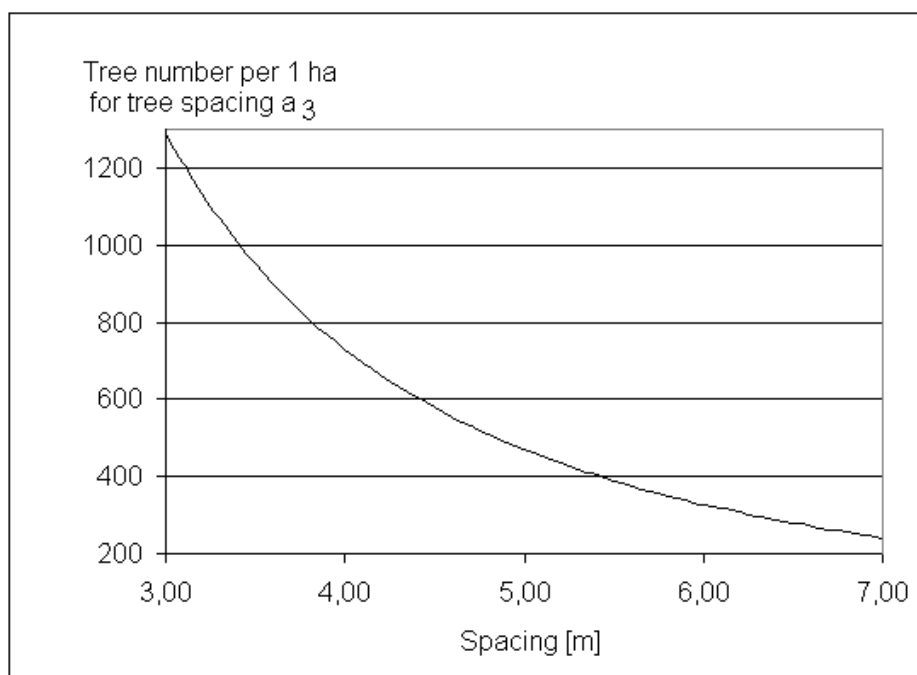


Figure 2. Interdependence of tree number on tree mean spacing.

2.3 Mean tree thickness

Mean thickness of vegetation D presents its thickness maturity, in most cases expressed as the thickness of mean trunk responding to the circular base of mean tree of vegetation given or, it is possible to define it as the weighed arithmetic mean and then it is the arithmetically determined mean thickness.

Mean thickness frequently tends to be related to the age of vegetation. These relations are presented by slightly concave curves closely approaching to a straight line. In the following, there exists a very important relation between mean thickness and quality of habitat. Generally speaking, we can say that with lowering quality of soil, the mean thickness also decreases.

Frequently the thickness maturity of vegetation is considered over distribution of tree frequency in height of 1.3m ($d_{1.3}$). This distribution can be presented by the use of known Gauss curve. Distribution of tree thicknesses is frequently a left-handed asymmetric one [9, 10, 11]. Relation [1] depicts the number of trees in dependence on stem diameter and mean spacing's:

$$N = B \cdot x^{-k}, \quad (3)$$

where N is tree number, B , k are constants and x is mean trunk diameter or tree mean spacing (see Fig. 3).

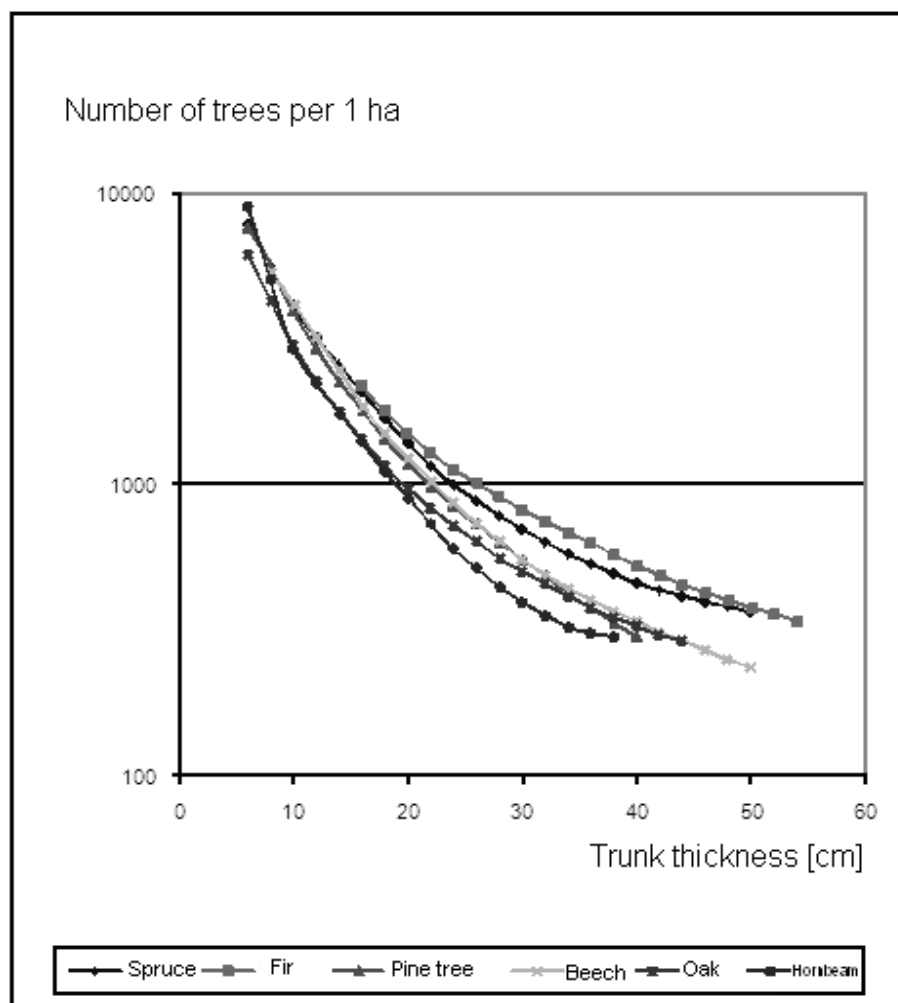


Figure 3. Number of trees per ha in dependence on trunk thickness.

2.4 Mean tree height

Mean height H tends to be considered for the rate of height maturity of vegetation. In practice, we understand this to be the height of mean trunk of woody plant species given.

In addition to mean height, the top height of vegetation is presented in [3, 5, 8, 11]. Its definition is not unified at the present time, but we can say that it is as a rule the mean height of a certain number of the thickest trees of vegetation given.

The height of mean trunk is mostly expressed in dependence on vegetation age. That way we can obtain so called curve of growing (developing). Generally, this curve rises from the beginning relatively quickly, but at the higher age flattens out. (see Fig. 4).

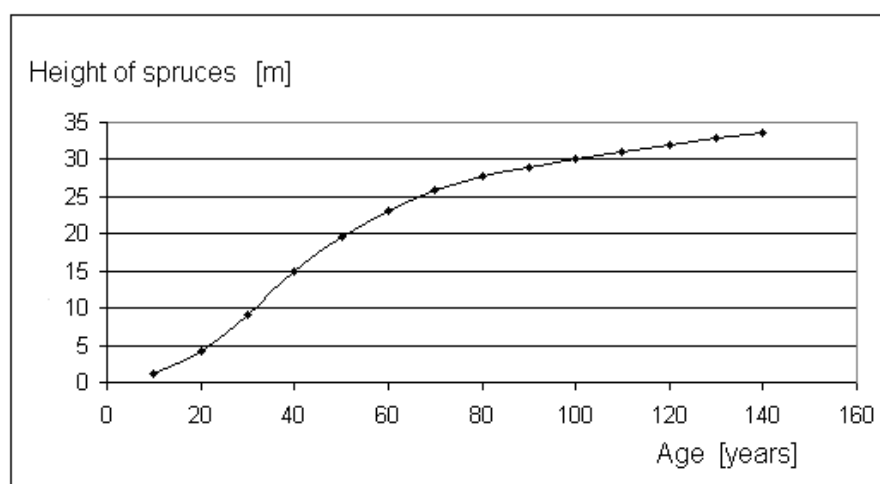


Figure 4. Process of height growth of a spruce forest.

Height growth of woody plants depends primarily on habitat quality, which is exploited at enumeration survey by use of its height and age. Generally, we can say that the better habitat of woody plant given, the better also the mean height of vegetation.

3. Results and discussion

The described methods were tested on a spruce forest stand, located in the south-eastern part of the Czech Republic, northeast of Brno. This spruce forest was chosen because it is the most common tree species in many countries located in central and northern Europe. The current age of this forest is about 40 years. To determine changes in the canopy height, distances among trees and tree diameters the series of aerial photographs were used. The photographs were acquired during the military topographic maps up-dating periods from 1973 to the present. In addition the DSM with an average density of 1 point per square meter was used to compare both data sources (aerial photographs and laser data). This DSM was generated from LIDAR data in 2013. Comparing the heights of corresponding trees on the aerial photographs of various ages, the statistical sets of the tree growth rate were obtained. These statistical data and LIDAR data (2013) were compared with the growth curve of the spruce forest (Fig. 4), which corresponds to a similar natural environment (soil quality, climate characteristics, geographic location, etc.). The results of the measurements in a representative spruce forest and statistical calculations show that the tree growth curves rises relatively quickly from the beginning (young canopy), but becomes more flattened at the higher age. The results of this experiment show – see Fig. 5, which this method is fully applicable for the DSM generated from LIDAR data.

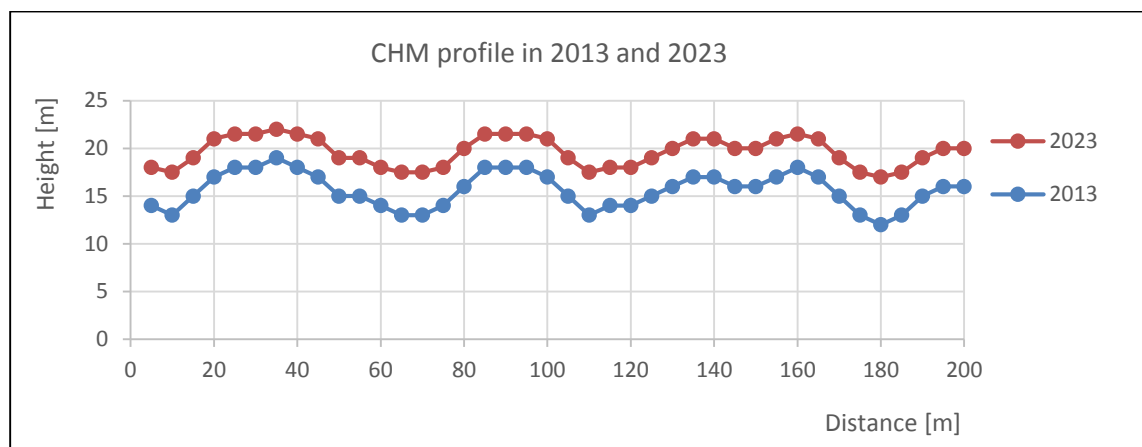


Figure 5. LIDAR CHM profile of a spruce forest in 2013 and predicted profile in 2023.

4. Conclusions

The method can be appropriately implemented as a relatively cheap up-dating tool in the GIS technology between two laser scanning campaigns of a territory. This method can also be refined using the growth curves of individual types of trees. It is also necessary to search the relationships between the natural environment factors and the specific canopy growth.

To determine the changes in the canopy height also the series of aerial photographs can be used. The photographs were acquired in the Czech Republic during the military topographic maps up-dating periods from 1973 to the present. In addition the DSM with an average density of 1 point per square meter can be used to compare both data sources (aerial photographs and laser data).

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