THE ACCURACY AND POSSIBLE USES OF A STAND HEIGHT MAP DERIVED FROM A DIGITAL SURFACE MODEL

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ABSTRACT

Stand height is a widely used index but it is rather time-consuming to obtain by field measurements and is often not available for larger areas as a continuous surface. In this paper we examine the possible uses and accuracy of DSMs created with the ATE and NGATE modules of a SOCET SET workstation in measuring stand height. We have created a stand height map for a sample area in the Bükk Mts for the years 1964 and 2004 in order to demonstrate the possible uses of such a time-series. Meanwhile we also examined the accuracy of the stand height map created for the Haragistya-Lófej Forest reserve, in Aggtelek Mountains. We compared the results of the automatic terrain extraction methods to manual photogrammetric measurements and the data of a field measurement. Our results show that both automatic terrain extraction methods give similar results to the manual photogrammetric measurements; however their accuracy depends much on stand type.

Keywords: stand height, digital surface model, stereo-photogrammetry, automatic terrain extraction

1 INTRODUCTION

Photogrammetry is an art and science technology in which the geometric properties of objects are determined from aerial imagery. E.g. the three-dimensional coordinates of points on an object are determined by measurements made in two or more images taken from different positions. The BAE SYSTEMS SOCET SET Automatic Terrain Extraction (ATE), and the Next Generation Automatic Terrain Extraction (ATE) modules used for this analysis measure elevation data automatically from the terrain, and create a digital surface model from measured points, which includes the height of natural and artificial objects on the surface as well as the elevation. The ATE and NGATE modules use an automatic stereoscopic technology based on area-matching. The new NGATE module uses both area-based and feature-based matching to generate 3D models. The theory behind NGATE and the algorithms associated with it have been described in for example Zhang *et al*. (2006) and Zhang (2006).

Our aim was to examine the potential of Digital Surface Models (DSM), derived from aerial imagery with the ATE and NGATE modules in the measurement and monitoring of stand height. Since a Digital Surface Model includes the height of natural and artificial objects on the surface subtracting the DEM from the DSM in a forested area will result in a stand height map (Waser et al 2006). The creation of the digital surface model being automatic this method could be useful in the monitoring of large forested areas; it also uses existing information sources such as aerial imagery and thus retrospective analysis becomes possible. In this paper we examine the possible uses and accuracy of such a stand height map on the example of two mountainous sample areas situated in Hungary.

2 DATA AND METHODS

2.1 STUDY AREA

Haragistya-Lófej Forest Reserve is situated on a dry karst plateau at 500 m above sea level, in the strictly protected zone of Aggtelek National Park, Hungary (Fig. 1). Its surface is dry and highly varied, covered by series of dolines and dry valleys. The sampling points are situated in the south-eastern part of the plateau where the bedrock mainly consists of dolomite.

The vegetation is a mosaic of dry thermophilous oak forests dominated by *Quercus pubescens*, oak-hornbeam forests and beech-hornbeam forests in smaller patches in the valleys. The most common species are *Carpinus betulus*, *Quercus petraea*, *Quercus pubescens* and *Fagus sylvatica*, often accompanied by *Acer campestre* and *Sorbus torminalis*. According to the management plans the age of these forests varies between 55 and 100 years.

Őserdő Forest Reserve, one of the very few old-growth beech forests in Hungary is also situated on a dry karst plateau in Bükk Mts at 800 m above sea level. This 59.3 ha forested area has not been managed for the last 200 years.

Figure 1. The location of the study areas

2.2 DATA

Field measurements were carried out with a Vertex III instrument on 3 occasions in 31 sampling points. 27 of these are situated in a 50*50 m grid where all trees with a dbh > 5 cm were measured in 10 m radius permanent plots; in case of the remaining 4 points the nearest 20 trees were included (Fig. 2). After excluding snags 654 trees were included in the database, which also contains data on the crown class (according to Kraft's classification), dbh and species of the individual trees. Some 20 trees were measured 2-3 times from different directions in order to define the approximate error of the height values; the average difference was 1 m (7%).

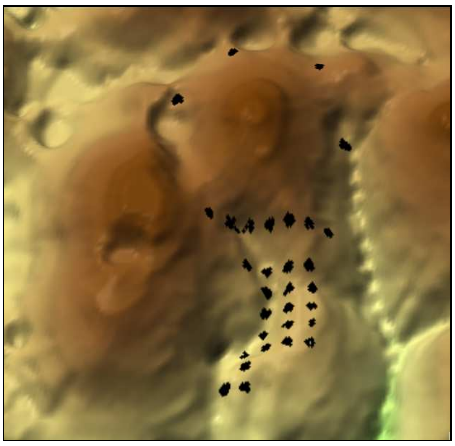

Figure 2. The sampling points in Haragistya-Lófej Forest Reserve

The negatives of the aerial photos used for the analysis were digitised with a Z/I PhotoScan 2002 scanner with a resolution of 14 µm. Approx. 1200 tree heights were measured manually in the vicinity of the sampling points using the ITE (Interactive Terrain Edit) module of the workstation. According to our experience the error of such measurements is generally 3 times the field resolution, in this case 1:30000, which means 1.8 m in average. When creating the DSMs with the ATE and NGATE modules, the default parameters were applied in both cases and the resolution was set to 2 m. One of the main differences between the results of the two is the spatial distribution of the resulting height measurements (Fig. 3). In order to show the difference the Cox index (Cox 1971) was calculated for both datasets using 4050 pieces of 100 m^2 squares. While the points generated by the ATE module are more aggregated (index value = 2.42), the points generated by the NGATE module are situated more regularly (index value = 0.38). For generating tree heights from the DSM a 10 m resolution DEM was applied. The error of this DEM in densely forested areas and highly varied surfaces can reach 5 m (Zboray, Kevei-Bárány 2004).

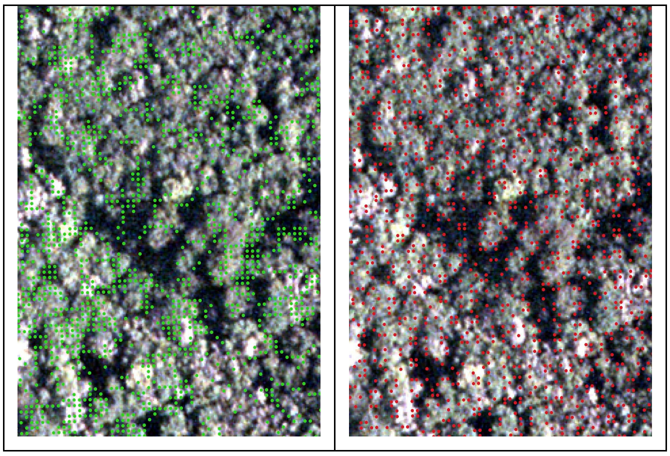

Figure 3. The spatial distribution of ATE (left) and NGATE (right) height measurements

2.3 METHODS

Although we're mainly interested in the error of the DSM, the differences between the heights measured in the field and the heights calculated with photogrammetric methods also contain the errors of the DEM, the field measurement and the localisation. In order to get an idea about the accuracy of the automatically created DSM, the surfaces created with the ATE and NGATE modules were first compared to the results of manual photogrammetric measurements carried out with the ITE module. First, the original values were compared then the tree heights were calculated by subtracting the height above sea level and these were also compared to each other by calculating correlations and the RMSE. Next the results of all 3 photogrammetric methods were compared to the measured tree heights. The sampling points were divided in categories according to stand type in order to find out how the different methods worked in the different stands. Paired samples t-tests were carried out for each group to see if the means differed. In most of the comparisons, only the trees of the upper crown layer were considered; those that belonged to the dominant, overstory or co-dominant crown classes according to Kraft's classification.

We used ArcView 3.3 and SPSS 11 software for the analysis.

3 RESULTS AND DISCUSSION

According to the results of the comparison of the ITE, ATE and NGATE data both automatically generated surface values showed very high, significant correlation with the manually measured surface value (Fig. 4). However when the computed tree heights were compared, the results were less favourable (Fig. 4).

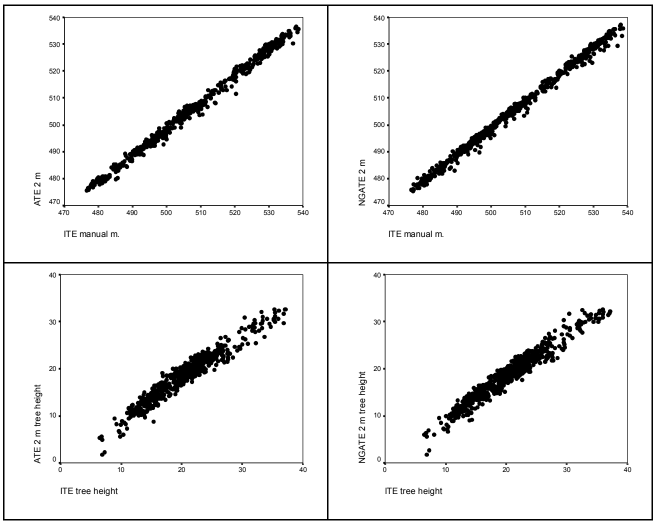

Figure 4. The comparison of the ATE and NGATE results and the manual photogrammetric measurements

The differences between the manual and automatic measurements have a higher mean and standard deviation than in the case of the surfaces. This is probably due to the low resolution of the used DEM and its inaccuracy. The RMS error is lower in the case of the NGATE module than the ATE module (Table 1). Apparently the inherent error of the automatic measurement does not remarkably exceed that of the manual photogrammetric height measurements neither in the case of the ATE module nor the new NGATE module.

Tables 2-3 show the results of the comparison of the 3 types of photogrammetric measurements and the field measurements. First, all the trees were included in the comparison. However, since the trees that do not reach the canopy layer are 'unseen' by any photogrammetric methods the difference between the photogrammetric and field measurements in the case of these can mount up to even 20 m. Then these trees were omitted from the database and the RMS error was reduced to 2.2-2.4 m; the lowest value was produced by the NGATE tree heights. Stand height can be considered the mean or mode of the heights of the individual trees, so next the means related to the sampling points were calculated and compared. These show considerably higher correlation values.

Table 1 RMSE of the manual and automatic photogrammetric measurements

	RMSE (m)
ITE-ATE surface	2.063
ITE-ATE tree	2.326
ITE-NGATE surface	1.711
ITE-NGATE tree	2.056

Table 2 RMSE of the photogrammetric and field measurements

	RMSE (m)		
	ITE	ATE 2m	NGATE
All trees	5.858	5.231	5.250
Dominant trees	2.420	2.287	2.291

Table 3 Pearson correlations of the photogrammetric and field measurements

	Pearson correlations*		
	ITE	ATE 2 m	NGATE
All trees	0.570	0.571	0.572
Dominant trees	0.671	0.692	0.690
Dominant trees - average	0.855	0.857	0.858

*Correlation is significant at the 0.01 level (2-tailed)

In the comparison of groups the two automatic methods (ATE and NGATE) produced similar results in all types (Fig. 5-8). In group 1 and 3, the oak-hornbeam forests and the beech-dominated stands the ITE values are slightly higher while the mean of the field measurements is lower but does not differ significantly from that of ATE. In the case of the beech forests it is important to note that in this group the number of dominant trees included in the analysis was only 19. In groups 2 and 4, the dry thermophilous oak forests and the recently reforested glades dominated by *Quercus pubescens*, the automatic methods give lower values than the manual ones and the latter have no significant differences between their means according to the t-test.

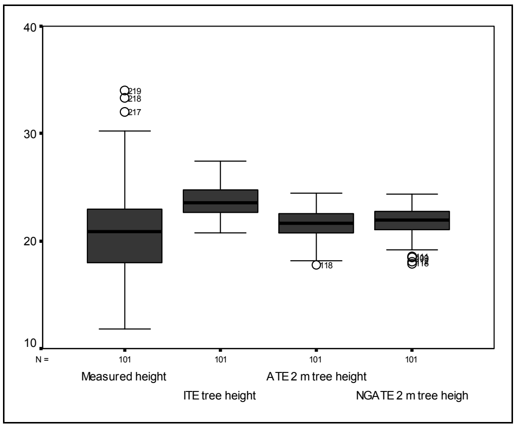

Figure 5. Tree heights acquired with different methods in oak-hornbeam stands

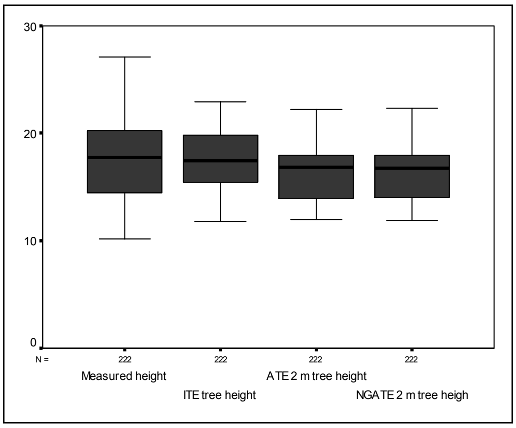

Figure 6. Tree heights acquired with different methods in thermophilous oak stands

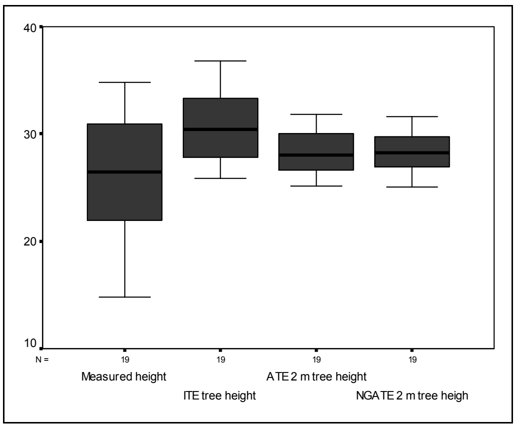

Figure 7. Tree heights acquired with different methods in beech-dominated stands

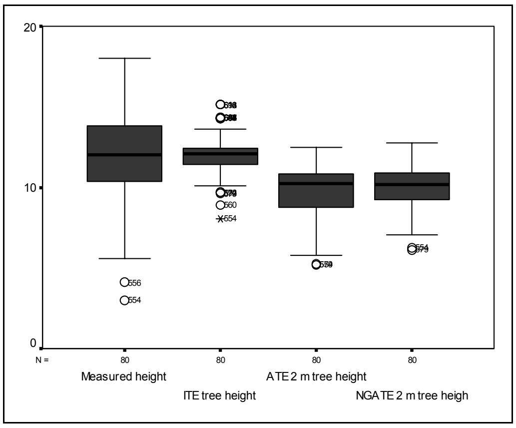

Figure 8. Tree heights acquired with different methods in recently reforested glades dominated by *Quercus pubescens*

These results show that the automatic methods work better in dense stands. Field measurements produce lower results in such stands because of poor visibility and the limits of the measuring instrument being close to the average height. The higher values of manual photogrammetric measurements are probably due to the fact that overstory trees are easier to measure.

In the more open oak-dominated forests the results of manual measurement techniques are very similar to each other while being significantly higher than those of the automatic methods. In such forests there is a higher probability of the automatic methods measuring the ground level instead of the canopy level. Thus in the interests of more accurate results the heights acquired automatically in such stands should be complemented with manual measurements before the surface is created.

3.1 RETROSPECTIVE HEIGHT ANALYSIS

In order to analyse the change in stand height we used DSMs created of archive and recent aerial images (Fig. 9). Since there has been no forest management activity in Őserdő Forest Reserve for 200 years any changes found must be natural. The tree heights were defined by using Automatic Terrain Extraction on 1:30000 field resolution aerial photos, in a 10 m grid. The histograms of the height values of 1965 and 2004 were then compared (Fig. 10). The mean height change is around 5 m, which exceeds the error of the automatically created DSMs calculated above and the similar shape of the curves suggests that over the examined 40-year-long period the forest has steadily grown and there were no significant changes in its structure.

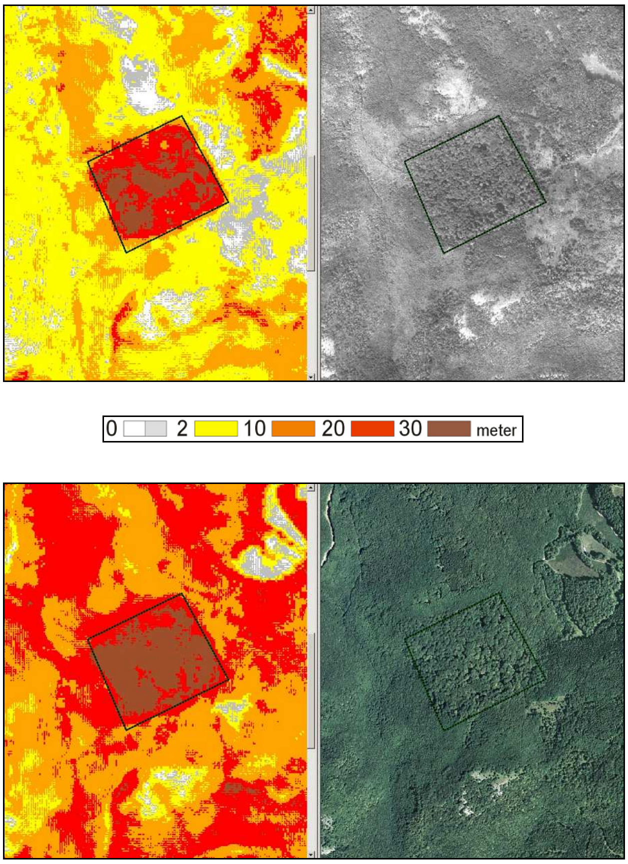

Figure 9. Tree heights in 1965 (upper) and 2004 (lower)

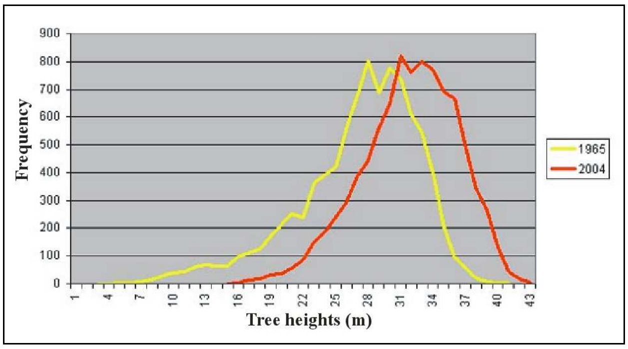

Figure 10. Changes in tree height frequency between the years 1965-2004

4 CONCLUSIONS

The comparison of the results of the ATE and NGATE modules and the manual measurements shows that the inherent error of the automatic methods does not remarkably exceed that of the manual photogrammetric height measurements. The comparison of the tree heights acquired with field measurements and photogrammetric methods predict stand height accurately enough as long as only the dominant layer is considered. The automatic methods work better in dense stands whereas in the case of more open oak-dominated stands they should be complemented with manual (either photogrammetric or field) measurements. The demonstrated change of the stand height in Őserdő Forest Reserve serves as an example of the usefulness of this research method in retrospective analysis.

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