

COMPARISON OF AERIAL PHOTOGRAPHS AND LASER SCANNING DATA AS METHODS FOR OBTAINING 3D FOREST STAND PARAMETERS

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ABSTRACT:

The aim of this study is an evaluation of the use of (semi-) automatic software solutions for the derivation of crown surface models and further forest information like vegetation height and vertical stand structure. It gives an overview of the up-to-date reachable accuracies of crown surface models and vegetation heights from traditional aerial images in comparison with the results from laser scanner data. Concerning the surface models, two algorithms (feature-based matching approach - ISAE and an area-based matching approach - RSG) were tested. The results were evaluated with three different methods. Despite careful investigations, the evaluations didn't lead to a definite preference of one of the algorithms. On visual interpretation, the ISAE seemed to be too smooth, while the RSG method produced higher errors within the single tree height measurements. For the area based comparison, both led to quite the same accuracies. Concerning the calculation of the vegetation height, the second main part of the study was the evaluation of the available terrain model. As the laser scanner terrain model could be used as ground truth, the difference is depicted through statistical figures. It turned out, that the official terrain model with errors of more than 10 m is not appropriate for measuring vegetation height. It can be summarised, that both photogrammetric algorithms lead to erroneous results in forest stands with a strong, but small-patched vertical structure, but to good surface models in quite homogeneous stands. In combination with an accurate terrain model – for example derived by laser scanning - the mean stand height for these parts can be calculated with an appropriate accuracy.

1. INTRODUCTION

Aerial images have long been successfully used for measuring various forest inventory and environmental parameters. Forest parameters that can be derived from aerial photos are for example tree species, tree age, crown closure and forest health. By means of photogrammetric methods additionally three-dimensional information such as vertical stand structures can be obtained.

It is obvious, however, that not all important forest parameters can be derived from aerial images. Significant shortcomings have been identified in mapping the terrain surface characteristics and terrain roughness beneath vegetation stands, which can provide the basis for assessing tree or stand height, for the planning, construction and optimisation of forest road networks or for the assessment of avalanche risk in alpine protection forests. Another problem is that automatic photogrammetric methods available on the market are not appropriate for the derivation of detailed tree wise information or to measure vertical structures within the vegetation stand. This is due to the fact that parts of the tree crowns are shadowed and the "visible" shape of a tree is varying due to its geometrical position on the stereo images.

The parameters "terrain roughness" and "vertical stand structure" can basically be derived from airborne laser scanner data as not all laser pulses will be reflected on the vegetation surface, but a significant proportion will penetrate into the interior of the vegetation stand and will be reflected by the ground surface and by vegetation layers within the stand.

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2. OBJECTIVES

In the paper the potential of aerial photos and laser scanner data for the assessment of vertical forest stand parameters such as terrain roughness and tree/stand height will be discussed. Additionally digital terrain models of forested areas resulting from laser scanner data will be compared with digital terrain models of the Austrian Federal Mapping Agency. For the processing of the aerial photos the software packages Intergraph (ISAE) and RSG (Remote Sensing Software Package Graz) were used. The processing of laser scanning data was performed with the Software IMPACT. Both, IMPACT and RSG were developed at the Institute of Digital Image Processing of Joanneum Research. The results presented are derived from the project "Derivation of Forest Parameters by Means of High Resolution Remote Sensing Data" which was financed by the "Styrian Woodcluster" (Hirschmugl et al. 2004).

3. DATA AND TEST SITE

The investigation was performed on the base of laser scanner data and aerial photos covering our test site "Burgau" located in the eastern part of Styria. The test site is characterized by hilly and flat terrain. The main tree species are beech (*fagus sylvatica*), oak (*quercus* sp.), spruce (*picea abies*), pine (*pinus sylvestris*) and larch (*larix decidua*). The relief varies from flat to hilly. The forests are mainly owned by farmers and thus play an important economic role in this region.

The laser scanner campaign was carried out in the year 1999 using the TopoSys scanner because of its high measurement

density, steep viewing angle and capability of providing both first and last pulse modes. The data captured during this campaign comprises:

First pulse: 23.8.1999; flight height 800m; 4-5 points per m²

Last pulse: 26.3.1999; flight height 800m; 4-5 points per m²

Infrared aerial photos were taken of the same area in the year 1998 at a scale of approximately 1:15.000 to 1:17.000.

Additionally, a digital terrain model (DTM) of this area with a horizontal resolution of 10 m was purchased from the Federal Calibration and Survey Office (Bundesamt für Eich- und Vermessungswesen = BEV) in Vienna. The Z-accuracy (height) of this DTM is officially specified between ±5 m and ±20 m for forested areas (BEV).

4. DIGITAL TERRAIN AND SURFACE MODELS DERIVED FROM LASER SCANNER DATA

In this chapter a brief description of the method used for the derivation of DTMs from laser scanner data will be given. The laser DTM will be used for the quality assessment of the DTMs available at the Federal Austrian Mapping Agency. More detailed information on the filter method is given in Ruppert et al., 2000; Wack et al. 2002 and Ziegler et al. 2001.

Raw last pulse data were processed in a regular 1 x 1m grid using a multi-resolution method in combination with an improvement by the integration of gradients. The method searches in a first step the raw data for the minimum values within the respective resolution and increases the minimum by an appointed amount as a function of the gradient in the neighborhood. Smoothing and thresholding algorithms are performed in each resolution step, thus resulting in corresponding pixel values. The method starts with a coarse resolution (e.g. 10 m) and compares the results with better resolutions (e.g. 7, 5, 3, 1 m) step by step. Hence, the method allows forest floor information to be obtained even in dense stands, as it is assumed that within 10 x 10 m at least one laser signal comes from the ground. The multi-resolution method - decisions whether to take the coarse or better resolution are made by thresholding - assures that ground results are taken from better resolutions whenever there is a ground signal, in other cases (dense stands) the value from the coarse resolution is taken. The accuracy obtained by more than hundred terrestrial GPS and geodetic measurements varies between 18 and 45 cm. The high accuracy of the DTM's derived from laser scanner are precise enough to use it as "ground truth" for the quality check of the relatively rough DTM's of the Austrian Mapping Agency.

5. PROCESS FOR GENERATING A SURFACE MODEL FROM STEREO AERIAL PHOTOGRAPHS

For the purpose of constructing crown surface models from stereo aerial photographs, the software packages Intergraph (ISAE) available at the Institute for Remote Sensing and Photogrammetry of Technical University Graz and the software RSG (Remote Sensing Software Package Graz) developed at the Institute for Digital Image Processing of the Joanneum Research were tested. The description of the methods focusses on the matching processes and 3D reconstruction available in

the two software packages since it is primarily these image processing steps that determine the accuracy of the resulting surface models.

Process steps preceding the matching, carried out with the Intergraph software, were 'image orientation' as well as a rough registration of image pairs for minimising parallaxes. This latter process step limits the search area for image correlation and increases the obtainable matching accuracy.

5.1 Building a surface model with ISAE (feature based matching)

For calculating the elevation model, the ISAE process employs a "feature based algorithm" which is used step by step within the pyramid structure ("coarse-to-fine strategy"), (Kraus, 2000). On each level of the pyramid homologous pixels are extracted. This is used to form 3D intersections in the object space and generate a DTM from bilinear finite elements. ISAE projects individual mesh elements of a baseline DTM (the baseline is a horizontal plane through a point in the centre of the area to be processed) into the image and thereby generates the homologous image areas.

It means that for each image a list of possible intersections is generated. Then these lists of characteristics are compared with each other and a search is carried out for suitable pairs of points for assigning to the image. For the similarity measurements, the ISAE uses the interest value and the correlation coefficient calculated with the help of the Förstner operator (Förstner, 1986). This process is carried out for each of the image levels within the image pyramid. The points thus found are entered into the next finer level of the pyramid. At the end a 'least squares matching' is carried out on the finest pyramid level in order to further improve the accuracy of the image correlation. In detailed tests it was possible to show that the highest accuracies are achieved with the following parameter settings:

Epipolar line distance: for this purpose the parameter 'epipolar line distance' (ELD) indicates in which epipolar lines 'feature points' are searched for in the image, and it therefore influences the number of points. The best results have been obtained with an ELD of 1.

Parallax bound.: indicates a limit value in the object space in which measured 3D points are included in the calculation (maximum height difference between individual points). The best results were obtained with values around 20.

Size of correlation window: 5 x 5 pixel

Number of pyramids: 10

Grid width X/Y: defines the step intervals of the DTM grid in metres. The best values were obtained with a step interval of 2 metres, which is for the present data the smallest achievable step interval in Intergraph.

Smoothing weight: defines the degree to which the terrain model is smoothed in the reconstruction process. Since for the purpose of this study it was important to maintain 'sharp edges', which were the result of e.g. gaps between adjacent trees, clearings or edges of the forest, this parameter was given no weighting (smoothing weight 1).

5.2 Reconstructing a surface model with RSG(area based matching)

A further surface model was calculated at the Institute for Digital Image Processing of the Joanneum Research Society in

Graz using the RSG software (RSG field guide) and using a hierarchical correlation algorithm which was also based on pyramid levels. This was a plane-based approach and the correlation method selected was cross correlation.. Detailed Information can be found in (RSG Feld Guide) and (Franke, 2004)

In order to optimise the matching results, all results with a back matching distance of larger than 3 were filtered out. In a further step, a weighted grid interpolation (weighted mean) of the irregularly distributed points cloud was carried out. Below we list the parameters with which the best results were obtained.

Number of pyramids: 7

Size of reference window: 7 x 7 pixel

Size of search window: 121(col) x 41(line)

Grid width: pixelsize of the scanned image

6. COMPARISON

In this section we will, on the one hand, compare the crown surface models obtained with the laser scanner data with those obtained with stereo aerial photographs. In addition, we will investigate whether it is possible to determine the height of trees or the vertical forest stand structure from a combination of the terrain models of the Federal Calibration and Survey Office (BEV), which are available on a nation-wide level, with the crown surface models derived from the stereo aerial photographs. Since for this purpose the quality of the BEV models is an important prerequisite, these models are compared with the digital terrain model obtained from the laser scanner data.

6.1 Comparison of crown surface models

The crown surface models (RSG, ISAE and laser scanner models) are visually compared on the basis of profiles that represent the different situations in the test site Burgau:

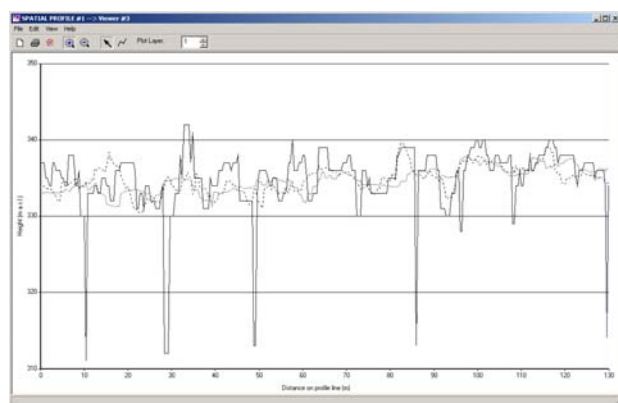


Figure 1. Profile of homogenous conifer stand, mean/strong timber

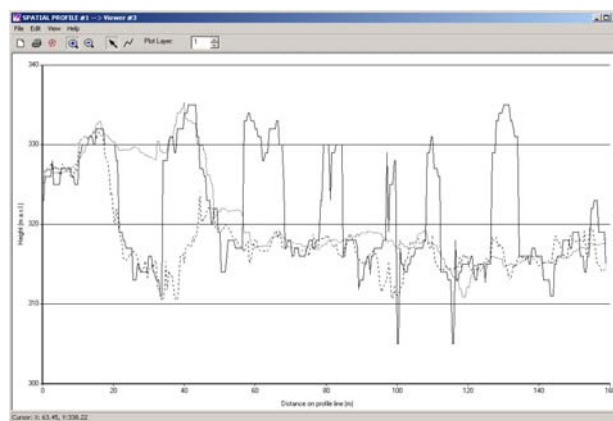


Figure 2. Profile of: heterogenous conifer stand, thinning and mean timber

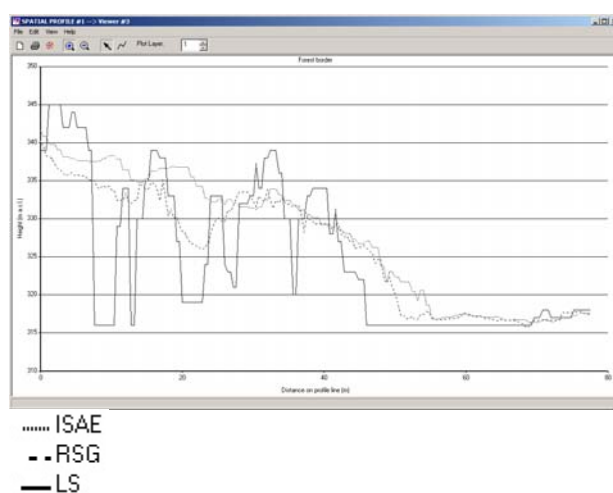


Figure 3. Profile of: forest border

The profile lines in profile 1 (figure 1) show that both models provide a good representation of the average stand height in a dense homogenous stand. The ISAE model is a bit more smoothed. Of course, compared to the laser scanner data, it is not possible to 'see through' to the forest floor. However, when using detailed topographical models, both approaches provide good results for determining the average stand height.

The profile lines in profile 2 (figure 2) show that it is normally not possible to record individual trees (such as e.g. single trees) with either the RSG or the ISAE method. If in some instances this can be achieved, the value between the two standards is subject to interpolation, which leads to an inaccuracy for the value of the height in between (see figure 2 between a distance of 20 and 40 m). This results in inaccuracies of 10 m and more in both methods and the surface models have in these cases only limited value.

The profile lines in profile 3 (figure 3) show that the edges of forests are displayed very differently by the different models. Naturally, the laser scanner model displays the optimum boundary by showing a steep edge on the edge of the forest. By contrast, the other two models 'fudge' the edge to varying degrees and thus lead to inaccuracies in the vegetation height both in the forest, where the values are too low, as well as outside the forest where the values are too high.

The results of the visual comparison of the profile lines can be summarised as follows: the vertical structures of individual trees are well depicted in the laser scanner data but are only scantily shown in the crown surface models based on the stereo aerial photographs. This is particularly the case where there are differences in height with only small gaps or taking up only small areas, such as e.g. in stands with great variations in vertical structure, where there are boundary areas between stands of different ages, or at the edges of forests. In addition, it became apparent (see e. g. figure 1 between 70 and 90 m, figure 3 at 20 m distance) that this “smoothing effect” was more pronounced in the crown surface models created with the ISAE software. This is due to the smaller grid width of the RSG model, so the stand structure can be mapped with more detail.

A quantitative evaluation of the different methods for the creation of crown surface models was carried out, firstly, by an area-based comparison of absolute heights in different forest stands and secondly, by comparing the height of 43 reference trees that were measured in the terrain. The results of the area-based comparison are shown in table 1, the results of the comparison with the reference trees in table 2.

Type of forest stand	Average difference between RSG and LS surface models [cm]	Average difference between ISAE and LS surface models [cm]
Young homogenous conifer stand (approx. 85 x 100 m)	290	289
Heterogenous multi-layer conifer stand (approx. 150 x 150 m)	500	493
Single-layer dense deciduous/conifer stand (approx. 140 x 150 m)	263	267
Old structurally differentiated conifer stand with clearings (approx. 165 x 100 m)	771	745
Old deciduous stand without clearings (approx. 70 x 60 m)	206	207

Table 1: Average differences in height (unit values) in selected stands between the RSG and ISAE models respectively and the heights obtained with laser scanning

	RSG	ISAE
Amount of average error [cm]	817	743

Table 2: Average error in the determination of the height of 43 reference trees in crown surface models created with the photogrammetric methods (RSG and ISAE) compared with terrestrial measurements.

The results listed in table 1 show that the height values of the photogrammetrically derived height models are at variance with the height values of the laser scan models. Of course, these deviations are due, on the one hand, to the laser scanner values penetrating the crowns and scanning the floor. On the other hand, these deviations are also the errors inherent in the

imaging of the crown surface. The results also show that the deviations are less pronounced in the case of more homogenous conifer forests and deciduous forests with less differentiations in the vertical surface structure compared to those of stands with strong differentiations in the vertical surface structure. Old stands with lesser density also show high errors, but this might be only because of the higher amount of terrain points mapped by the laser scanner.

Table 2 shows the comparison between the terrestrially measured trees and the vegetation heights from the different calculations. The terrain model used for the derivation of the vegetation height was in both cases the one based on the last pulses from the laser scanner.

The average error from the RSG-based calculation is slightly more than 8m and hence a bit greater than the ISAE-based calculation with approximately 7.5m. Therefore this comparison indicates that the ISEA software is to be preferred.

6.2 Comparison of terrain models

The determination of vegetation height, which is one of the relevant parameters from the forestry point of view, requires not only a crown surface model but also a terrain model. Since we cannot assume that laser scanner data are available for all areas, it is intended to check the available BEV model to see whether it is suitable for this purpose. Therefore as already mentioned the laser scanner model was used as ground truth. So, the BEV-terrain model was subtracted from the laser scanner terrain model. The following table (Table 3) shows the statistical parameters of the resulting difference image. That means the maximum differences are 34 m and approx. 9 m respectively. In general, the BEV terrain model tends to result in too high values.

Minimum [cm]	Maximum [cm]	Mean value [cm]	Standard deviation [cm]
-3400	881	1033	860

Table 3: Statistical parameters between the laser scanner floor model and the BEV terrain model

With an average deviation of over 10 m the quality check corresponds to the BEV statements. This means that this terrain model is not suitable for the determination of the vegetation height since the errors are too large. It also means that when using photogrammetric methods for forestry purposes it is necessary to employ an accurate terrain model such as can be created from laser scanner data.

7. SUMMARY

In this study we have tested two different algorithms for creating crown surface models: RSG and ISAE. Both were subjected to a quality assessment, comparing them with laser scanner data and terrestrial surveys of trees and also carrying out a visual interpretation. When visually assessing the profiles created for the two methods, the ISAE provides a somewhat more smoothed surface model compared to the RSG. This has a negative effect, particularly in areas covering the edge of the forest.

With respect to the quantitative error in establishing the vegetation height of more structured crown surface, both algorithms led to similar results, when comparing with terrestrially surveyed reference trees, the average error of ISAE

is smaller. Both models are generally not capable of recording and displaying differences in level that extend only over a small area and are therefore not suitable for measuring the height of individual trees. However, in combination with an accurate terrain model the average height of forest stands can be determined very satisfactorily. In the comparison of the terrain models we were able to confirm that, under forest stands, the BEV model produced errors of over 10 m and is therefore not suitable for the determination of the height of forest stands.

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