COMPARISON OF DIGITAL STAND SURFACE MODELS OF HRSC-A (HIGH RESOLUTION STEREO CAMERA - AIRBORNE) AND LASER SCANNER FOR FOREST STAND CHARACTERISTICS

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KEY WORDS: Surface Model, Stand Roughness, Forest Inventory, Tree Height, Semivariogram, Laser, HRSC-A, Dendrometer.

ABSTRACT

This work aims to assess differences between HRSC-A (High Resolution Stereo Scanner – Airborne) and TopoSys laser generated tree heights and digital stand surface models. Individual tree heights in surface models of coniferous and deciduous forests were compared with dendrometer measured (ground based) tree heights. Digital surface models (DSM) of TopoSys laser scanner and HRSC-A of spruce stands were compared calculating roughness quotients and multi-directional semivariograms. Roughness of stand surface and visibility of ground height in dense stands were examined. Results indicate that spruce stands were modelled more accurate with the laser scanner system. Variogram analysis revealed differences in multi-directionality and semivariogram range. Deciduous stands with dense crown tops can be assessed more accurate than coniferous stand surfaces with HRSC-A surface models. Individual tree heights of coniferous spruce trees were measured more accurate with laser dendrometer but the comparison of deciduous HRSC-A surface models and dendrometer measured tree heights of deciduous trees (beech) are promising and suggest HRSC-A digital surface models for further analysis of deciduous forest stand types.

1 INTRODUCTION

Tree height is an important stand parameter in forest inventory. It is used to calculate stand volume, mean stand height and resulting parameters (Kramer, Akca, 1995). Additionally tree height gives a structural description of forest stands which is crucial for the understanding of forest ecosystems.
Laser scanner technology has proven to be a reliable tool for topographical surveys with vertical accuracies equivalent to traditional land surveys. This technology has also great potential for applications in forestry as multiple reflections from ground and vegetation tops can be acquired. This eases the generation of forest stand height models assuming that the last pulse return is the reflection from ground (Hansen Von, Vögtle, 1999; Kraus, Rieger, 1999). Lefsky *et al.*(1997) and Means *et al.*(1999) verified the ability of SLICER (Scanning Lidar Imager of Canopies by Echo Recovery) to accurately measure canopy height profiles and to relate height profiles to stand structure attributes (height, basal area, biomass and leaf biomass). They concluded that large footprint airborne scanning lidar shows promise for characterising stand structure for management and research purposes. To similar results concluded Popescu and Nelson (2000) estimating biomass with SLICER data. One disadvantage of laser scanner data capture technology is the absence of georeferenced panchromatic or CIR (colour infrared) information of high geometric quality and resolution to aid the identification of objects and surface types. For forestry this implies the discrimination of stands that can be distinguished by spectral and spatial (texture related) characteristics more than by crown shape, tree height or stand surface structure. This problem becomes very apparent when ground control points or individual trees or other objects have to be located.
The HRSC-A provides (additional) high resolution panchromatic and multispectral information together with object heights with a relative accuracy of 15 cm (Wewel, Brandt, 1998; Neukum, Lehmann, 1997) for continuous surfaces. Investigating the use of both data types - HRSC-A surface models and high resolution multispectral information in airborne forestry remote sensing - is therefore of interest for developing new methodologies such as object oriented and multi scale image analysis strategies presented by Baatz and Schäpe (1999) and Hoffmann *et al.* (1999).

2 DATA AND TESTSITES

The HRSC-A is a digital multi-view angle camera system originally developed for the planetary MARS96 mission (Jaumann, Neukum, 1996). The nine CCD lines are arranged at specific viewing angles of which five provide the stereo imaging capability and four the multi-spectral information. Geometric resolution of 15 cm from a flight altitude of 3000 m is acquired. The HRSC-A applies the push broom principle (Neukum, Lehmann, 1997; Wewel, Brandt, 1998; Wewel *et al.,* 1998). The TopoSys system is a pulse modulated laser scanner system with a scope of 1000 m. The laser is emitting laser beams at a frequency of 83 khz with a scan frequency of 630 Hz. Absolute accuracy for xy is 3 m and for z is 50 cm. Relative accuracy for xy is specified with 50 cm and for z with 15 cm (TopoSys [1]).
HRSC-A data from May 1998 and May 1999 and TopoSys laser scanner data from July 1999 were used. Areas with spruce stands in the forest of Tharandt (16 ha) and with beech trees in the parc area close to Potsdam (Park Sanssouci, Postdam/Berlin) were selected. The digital surface model was processed to unsigned 16 bit with a z-resolution of 1 cm and xy resolution of 1 m. Laser scanner data for the ´Tharandter Wald´ was purchased in first pulse mode and used as processed by TopoSys. The HRSC-A data was processed in order to fit to the same grid size and projection (Gauss Krüger, Zone 4, Bessel, Potsdam Datum) of the laser data. The resolution of the geometrical pre-corrected HRSC-A data of 15 cm for nadir and 30 cm for the stereo channels was reduced to 30 cm for the multi-image matching. Optimation of the processing for forest stand surfaces was done by adapting the cross correlation window size to surface characteristics. After rejecting object points beyond a relative accuracy of 1 m from at least 3 stereo channels in every image correlation pass the resulting object points contributed to the final surface model. This method creates a less interpolated surface model as the density of object points is increased (Hese *et al*., 1999) but multi-image matching procedures have to be repeated for different correlation window sizes which increases the processing time considerably. In a second step an additional flight strip with overlap was processed. This doubles the available numbers of stereo channels in the overlapping image area and increases the number of resulting object points by 20% (Hese *et al*., 1999).
Heights of approximately 200 spruce (*Picea abies*) and beech trees (*Carpinus betulus L., Fagus sylvatica*) were measured ground based with a laser dendrometer (LEDHA Geo) in February 2000 to obtain reference height information. Additionally all heights were measured with a Blume-Leiss dendrometer to avoid mis-measurements. Tree identification was performed in HRSC-A nadir hard copies (scale 1:500) of the testsite visually and heights were attributed accordingly.

3 TOPOSYS LASER – HRSC-A DSM COMPARISON

For some spruce stands roughness quotients were calculated using the TIN (Triangulated Irregular Network) surface data format (calculating surface area and planimetric area) for laser and HRSC-A DSM to compare how discontinuous surface features in resulting surface models are mapped (Table 1). Higher quotients for the laser data indicate that surface minima (usually ground height) is interpolated to higher values in HRSC-A DSM.
Correlation analysis of laser and HRSC-A surface models of spruce show that coefficients are low, in particular for clear cuts (Table 2).

Surface quotient: ($Rq=A_{surface}/A_{planimetric}$)	Spruce stand 1	Spruce stand 2
HRSC-A	2,27	2,75
Laser	3,04	4,13

Table 1: Surface roughness quotients of spruce stands of laser and HRSC-A surface models.

Correlation Coefficient (r)	Clear cuts laser	Spruce stand laser
Clear cuts HRSC-A	0.322	-
Spruce stand HRSC-A	-	0.594

Table 2: Correlation coefficients of HRSC-A and laser processed digital stand surface models of a spruce stand and clear cuts (forest of Tharandt).

4 COMPARING SEMIVARIANCE OF SPRUCE DSM OF HRSC-A AND LASER

The semivariogram is a simple function for investigating spatial correlation of data in one, two or three-dimensional space (Miranda, *et al.* 1996). It describes how the spatial continuity changes with distance and direction (Isaaks, Mohan Srivastava, 1989). Image data with regular grid spacing of the data values can be analysed easily because no distance groups with associated tolerance have to be specified. Additional to different distances semivariance can also be calculated for single directions. Multidirectional semivariogram analysis can describe a two dimensional data set more accurate but results can be difficult to interpret. The semivariogram is computed as follows (1):

$$\gamma(h) = \frac{1}{2N} \sum_{i=1}^{N} \left[Z(x_i) - Z(x_{i+h}) \right]^2 \tag{1}$$

where h is the distance separating data location x_i from another location x_{i+h}. The Semivariogram computation starts with small h and increases to investigate the change of data values as a function of separation distance (Miranda *et al.,* 1996; Carr, 1995). Used originally within the mineral industry, applications of semivariogram statistics in remote sensing have been found very useful (Curran, 1988; Carr and Myers, 1984; Miranda *et al.,* 1996). St-Onge and Cavayas (1995) found semivariogram parameter related to tree size and stand density using panchromatic high resolution airborne data and Bruniquel-Pinel and Gastellu-Etchegorry (1998) used semivariogram statistics to study the impact of changing stand parameter of artificial forest scenes. They also concluded that a strong correlation between stand structure and texture exists when image resolution is better than 1 m.

Presuming that digital models of the stand surface are accurate enough to characterise a specific stand type the use of semivariogram statistics for DSM could aid to extract new information types of a stand that are shape related and not reflectance or contrast related. This is an important advantage as reflectance in high resolution image data is very much dependent on illumination characteristics and object shape and varies from one image to the next. This usually complicates all texture analysis.

For this work HRSC-A and laser surface models were compared using semivariograms with DSM of 1 m resolution, semivariogram cutoff at 40 m and steps of 45° for multi-directional variogram analysis with a directional tolerance of 5 degree. Resulting semivariograms of HRSC-A and laser data (Figure 1) show remarkable differences in all aspects of semivariogram characteristics (sill, range, multi-directionality and oscillation around its sill) (Table 3).

Semivariogram parameter	TopoSys laser DSM	HRSC-A DSM
Sill	285000	75200
Range	9 m	18 m
Semivariogram model	spherical	spherical (nested)
Multi directional character	anisotrop (hole effect)	isotrop

Table 3: Semivariogram characteristics of a HRSC-A and laser spruce stand surface model.

HRSC-A multi directional semivariograms are characterised by a nested structure. A nested structure is composed of a shorter range and a longer range value. The shorter range is the distance of the first obvious change in curvature and the longer range is the distance of a second obvious change. Nested structures usually indicate the presence of processes operating at different scale. The interpolation of surface values in HRSC-A DSM could have caused this effect. Multi directional semivariograms show identical shape which indicates that anisotropy in the surface model cannot be mapped with HRSC-A stand surface models.

The multi-directional semivariograms of the laser surface model (Figure 1) are difficult to interpret. The rise of the variograms above its sill value and the drop which follows is usually related to a hole in the covariance (Armstrong, 1998). This effect can be explained with periodic height minima between coniferous trees in stands with even aged trees and its shape is linked to tree density and size. Similar semivariogram shapes with more distinct oscillation around the sill occur with panchromatic high resolution data of forests. Shadows between trees contribute to this effect. The high sill values of the laser semivariograms can be explained with mapped ground heights and a resulting higher variance.

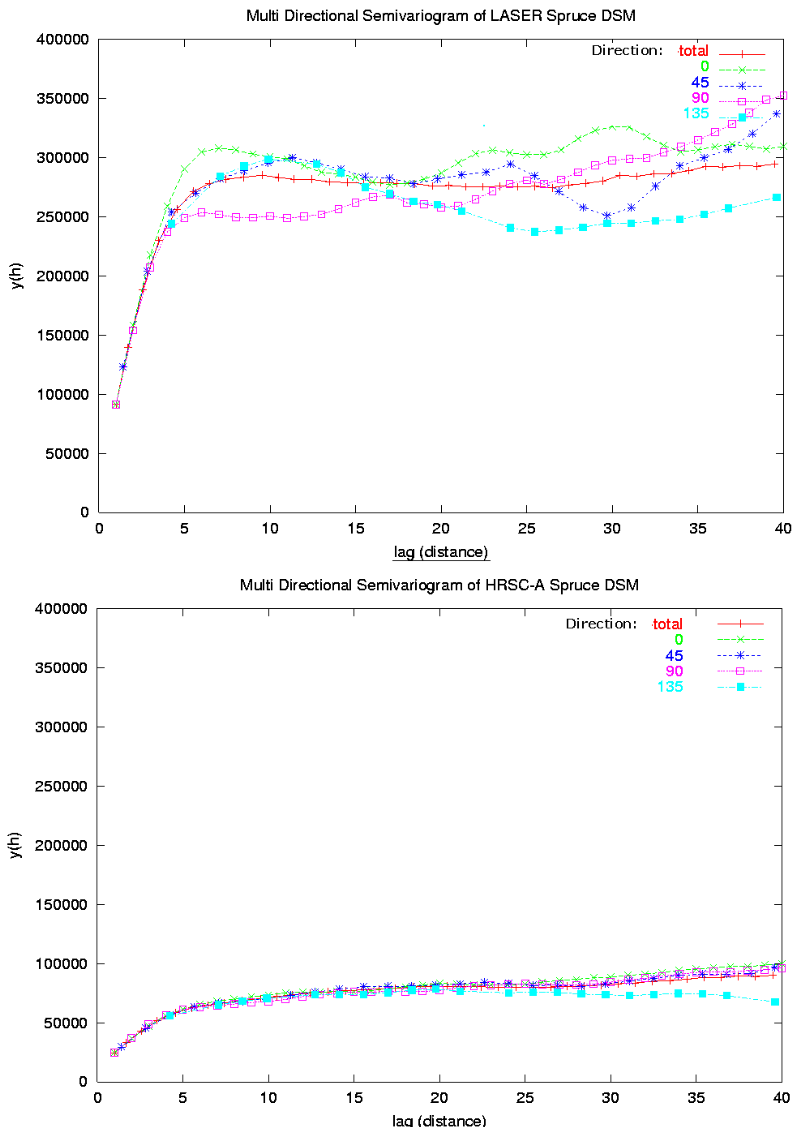

Figure 1: Multi-directional semivariogram of TopoSys laser and HRSC-A surface models of the same spruce stand.

5 COMPARISON OF HRSC-A AND LASER MAPPED TREE HEIGHTS WITH DENDROMETER HEIGHTS

Terrestrial measured tree heights of spruce and beech have been compared with laser and HRSC-A generated digital surface model heights. Approximately 200 individual trees were identified on panchromatic HRSC-A nadir data hard copies (scale 1:500) and height was measured with a Blume-Leiss and a laser dendrometer (Ledha Geo). The data was attributed manually to local maxima in the digital surface models. Trees were chosen that had an adjacent reference terrain height. Differences between adjacent terrain height and tree stem nadir were used to correct resulting levels.
HRSC-A spruce heights are underestimated (Figure 4) but highly correlate with beech tree levels (Table 4).
Laser generated heights of spruce tree levels are better correlated with dendrometer heights than HRSC-A heights and show less mean differences (Table 4). As the correlation coefficient is always effected by extreme pairs it should be noted that the absence of low tree heights of spruce trees has probably shifted the results of the predicted spruce model.

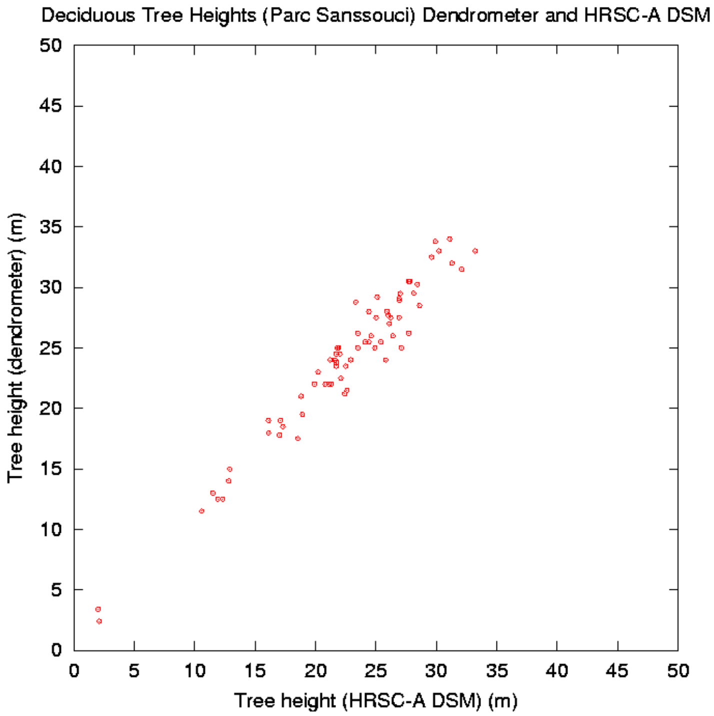

Figure 3: Scatterplot of dendrometer (ground based) measured heights and HRSC-A (DSM) measured heights of beech trees.

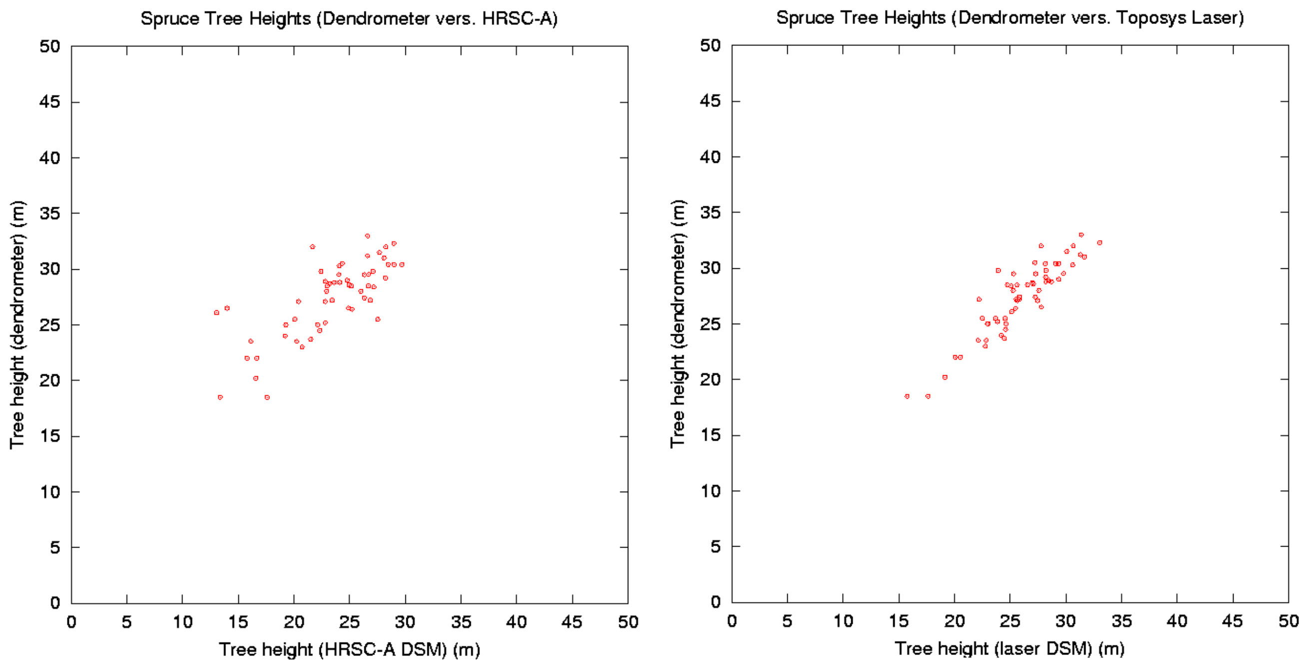

Figure 4: Scatterplot of dendrometer (ground based) measured tree heights and HRSC-A and TopoSys laser (DSM) measured tree heights of spruce trees (forest of Tharandt).

Stand type / sensor	Mean tree height difference (m)	Correlation coefficient (r^2)	Sample size (number of trees)	Predicted linear model
Spruce laser	1,32	0.922	75	4.2180 + 0.8868 x
Spruce HRSC-A	3,29	0.756	68	8.9051 + 0.7643 x
Beech HRSC-A	1,45	0.974	72	1.2738 + 1.0077 x

Table 4: Relationship between ground based tree height (dependent variable) and TopoSys laser and HRSC-A derived tree heights.

6 DISCUSSION

Ground measurements of tree heights were performed with a laser dendrometer (accuracy of ± 10 cm) and a Blume-Leiss dendrometer providing a lower accuracy of ± 50 cm. First experiences indicate that the laser distance measurements with the 'Ledha Geo' are not always reliable and should be checked regularly with a tape measure. The accuracy of the distance measurement of the laser dendrometer (Ledha Geo) which is one of the key parameter to calculate tree height is very sensitive to bark surface characteristics and atmospheric conditions. Additional height measurements were made in order to avoid mis mensurations.
Other measurement problems occur when estimating deciduous tree crown tops because pinpointing the top of the tree when using a dendrometer with angle mensuration is difficult to achieve. The top crown level is not directly visible. Doing the survey in non-foliated state can aid the interpretation process. The trend of the resulting misinterpretation is to presume that the crown top is located at the margins of the crown which overestimates the heights. These problems are not relevant for coniferous trees as the tops can be identified precisely. Errors introduced here are mostly related to very short distances between tree and measurement (dendrometer) position. Appropriate distances cannot always be found in dense coniferous stands.
The TopoSys laser scanner system with a point density of 25 measurements per sqm (flight altitude of 400 m) is a very qualified pulsed laser system for forestry applications. Usually measurement density is processed to geometric resolution of 5 to 20 m. Popescu and Nelson (2000) concluded in their work about forest biomass estimation using airborne lidar that a footprint better than 3 m for deciduous stands and better than 1 m for coniferous stands is needed to find local maxima that correspond to crown centroids.
Deciduous stands can be modelled with HRSC-A DSM accurately when stand crown surface is dense and therefore to a certain degree continuous. Efforts to optimize the HRSC-A data processing for coniferous stand types did not succeed.
A comparison of deciduous laser and HRSC-A DSMs could not be accomplished. Laser data was not available in time for this work but results are expected to join the statement that beech heights are mapped comparable accurate with HRSC-A digital surface models.

7 CONCLUSIONS

Digital surface models of HRSC-A and laser were used to investigate the accomplished tree height accuracy and stand surface character of beech and spruce stands.
Results show that HRSC-A DSM of spruce stands do not rebuild the spruce stand surface as characteristic as laser data can. This is mostly due to homogenous texture characteristics with repeatedly shadowed areas and very discontinuous and steep crown characteristics of spruce tree crowns. To this conclusion states also the examination of relative mean object point error in dependence of slope classes (Hese *et al*., 1999) and results of Wijanarto and Osborn (1998). Most of the height minima in the spruce stand surface detected by laser data were not mapped with the HRSC-A surface models though HRSC-A data processing was optimized using 10 different stereo channels of 2 flight strips.
Variance characteristics of laser - and HRSC-A DSM show different sill, range and different multi directional characteristics. This indicates that directional differences in spruce stand surface shape cannot be captured with HRSC-A digital surface models.
The position of breaklines in surface models is critical for the comparison of height statistics. Analysis of position and shape of these breaklines showed significant differences. In general HRSC-A DSMs show less steep slopes at breaklines of stand surfaces and at internal clear cuts of stands than laser data does. This indicates that surface roughness is not captured accurate enough.
Comparison of DSM heights and ground-measured individual tree heights suggest that HRSC-A digital surface models are not accurate enough to record coniferous tree heights. However deciduous stand surfaces are rendered

more accurate with HRSC-A surface models than coniferous. This can be explained with the dense and grown together character of old beech stands. The less steep slopes of the crowns reduces the shadowed portion in the image data and different view angles capture more comparable texture. These results suggest HRSC-A DSMs for investigations of deciduous stands.

Spatial information of high resolution multispectral and panchromatic HRSC-A data has already demonstrated promising results in conjunction with height information for object-oriented and multiscale image analysis (Hoffmann et al., 1999; Lehmann et al., 1998). Combined techniques using spatial, spectral and height information of HRSC-A data will be also of importance to investigate forest ecosystems in near future.

ACKNOWLEDGEMENTS

Dendrometer equipment was kindly provided by the Technical University of Dresden (Institut für Waldwachstum und Forstliche Informatik).

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