Characterization of forest stands using full waveform laser scanner and airborne hyperspectral data

Henning Buddenbaum[1] & Stephan Seeling[1]

[1]University of Trier, Remote Sensing Department, Behringstr., 54286 Trier, Germany, buddenbaum@uni-trier.de, seelings@uni-trier.de

Abstract

Full waveform airborne laser scanning was assembled into voxels and combined with airborne hyperspectral data. This combined data set offers a detailed insight into the structure and the reflective properties of tree stands. A comparison of stand photographs and aggregated full waveforms shows the close relation between the stand structure and the waveforms so that the potential of the waveforms to act as a key variable for remote sensing characterization of stand structure is evident.

Keywords: Full waveforms, hyperspectral data, hemispherical photos

1. Introduction

Full waveform airborne laser scanning (ALS) offers a maximum of information about the three-dimensional structure of forest stands. As the canopy elements of forest stands (leaves, needles, twigs, branches) are usually smaller than the diameter even of small-footprint laser scanners, the laser beam often is reflected several times inside a canopy so that a complex echo waveform results. In dense canopies this waveform contains information only about the tree crowns, in looser canopies there are also echoes from the ground.

The maximum of spectral information, apart from laboratory spectroscopy, can be obtained by airborne hyperspectral imagery (Vane & Goetz 1988). Both, full waveform airborne laser scanner data and airborne hyperspectral data are available for the study area, the Idarwald forest in south-western Germany. In this study, these two very rich data sets are combined to get a very detailed insight into the stand structure. These structural analyses are validated using fish-eye lens photography of many of the stands.

2. Material and Methods

2.1 Study area

The area of study (49°40’N, 7°10’E) is the Idarwald forest in south-western Germany on the north-western slope of the Hunsrück mountain ridge. The dominant tree species are Norway spruce (Picea abies), beech (Fagus sylvatica), oak (Quercus petraea) and Douglas fir (Pseudotsuga menziesii). Active forestry practices in this area include selective cutting, plantation establishment and thinning.

2.2 Data used

In July 2003 a Hymap image of the study area was acquired. The original data set contains 128 reflective channels in the spectral range of 440 to 2480 nm with spectral resolutions between 10 and 20 nm (Cocks et al. 1998). Due to noise six of the channels were eliminated. Data preparation steps included a cross-track illumination correction, a parametric atmospheric correction and a parametric geocorrection to the local Gauss-Krüger system (Schlerf et al. 2004, Buddenbaum et al. 2005).

In September 2005 laser scanner data was acquired using a Riegl LMS-Q560 (Hug et al. 2004) which records full waves. The data set is available as first echo, last echo and only echo single point files and as waveform data. The data provider filtered a ground point data set from the last and only echo files. Figure 1 shows all waves within a radius of 1 m around a point on the ground. A flight pattern with ten overlapping flight lines was chosen so that nearly all of the study area was seen from at least two angles. This is a commonplace flight pattern chosen in order to increase the probability of seeing ground pixels through dense crowns and to account for the asymmetry in canopy level data collected at varying scan angles (Hopkinson et al. 2008, Holmgren et al. 2003). Additionally, full coverage of the area could be guaranteed.

In addition to the remote sensing data, field work was conducted in September 2005. 28 stands of Norway spruce and beech were sampled in plots of 30 m × 30 m size. Parameters measured included tree height, crown height, crown radius in four directions, stem diameter at breast height, LAI (measured by a Li-Cor LAI 2000 Plant Canopy Analyzer), number of trees and canopy closure. Nine hemispherical digital photos using a fish-eye lens have been taken of each stand in order to document the stand structure.

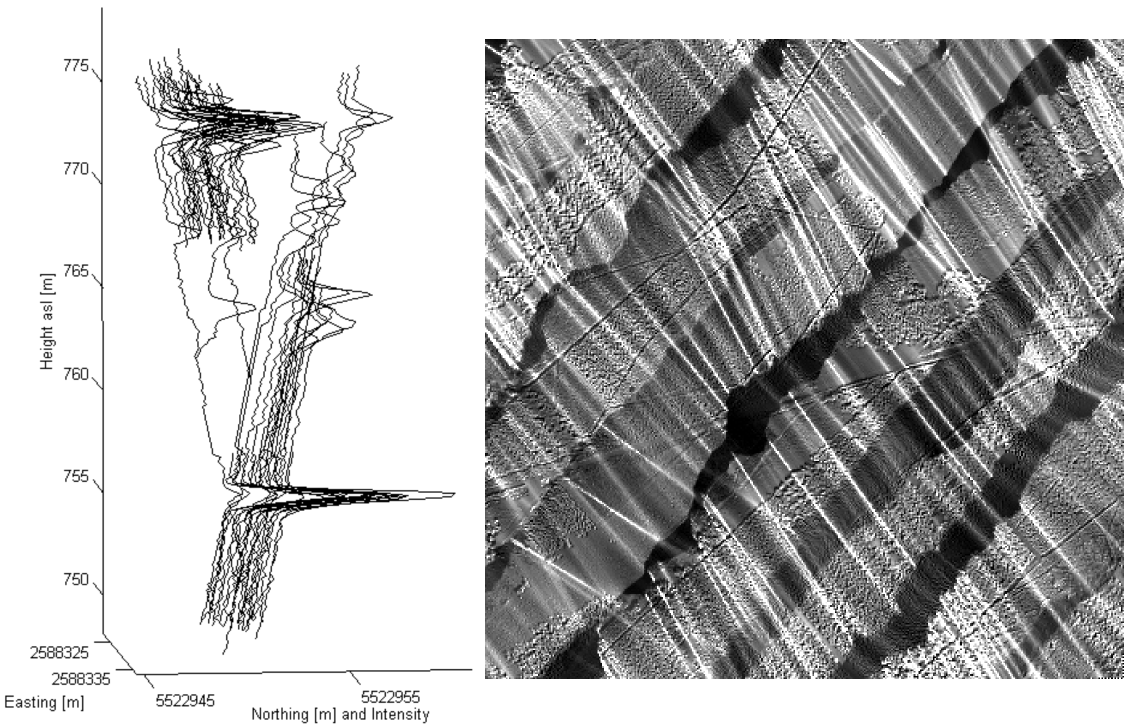

Figure 1: Left: Full waveforms from two flight lines converging on a small ground area. The ground level is at about 756 m asl where the lowest peaks occur. Right: Frequency of laser hits in an area of 400 x 400 Pixels; flight line overlapping and aircraft motions can be seen.

2.3 Methods

To reduce the amount of data and to align the full waveform ALS data to the hyperspectral data all waves within a ground area of 5 m x 5 m – the geometric resolution of the hyperspectral data – were combined. The data were to be expressed as voxels (volume elements, Figure) of 5 m x 5 m x 0.5 m volume. Each voxel contains the mean intensity with which laser pulses were reflected in the according volume element. As a basis for this combination a 5 m x 5 m DEM was created from the ground point data set. For every waveform the ground position was calculated. The intensity curve was interpolated to 0.5 m steps starting at the ground height taken from the corresponding ground pixel. All values within a voxel were added while a counter in another array was increased. At the end the accumulated intensities were divided by the number of hits per pixel, resulting in an average waveform for each pixel. The result was saved as a multiband file similar to the hyperspectral data set. This procedure took a processing time of about 5 days. As the maximum tree height in the study area is about 38 m, 76 bands were created. Only the highest stands contain data in the last bands; in clearings there are data only in the first band. All intensity echoes were assigned to the position of their ground pixel; in the creation of the voxel data set we did not consider the slanted view direction but treated all waves as if they had been recorded from nadir direction. This approach of creating a voxel data set is different from that of e.g. Popescu & Zhao (2008) as the voxels were filled with fullwave intensity data, not with single points.

The multiband ALS image and the hyperspectral image were stacked. The layerstack of hyperspectral and laser data contains 198 bands.
Figure 3 shows examples of Hymap-ALS "spectra". The left part of each graph is the reflection spectrum, the right part is the height profile of the pixel (or voxel). It is very difficult to recognize the age of a tree stand from the reflection spectrum alone; in combination with the ALS spectrum this becomes much easier. For example, the reflectance spectra in the upper right part and the lower left part of the figure are hardly distinguishable. In a classification they would very likely be put in the same class. Only the additional information offered by the ALS data shows the differences in stand structure clearly.
Figure shows more examples of the good accordance of ALS height profiles and the tree stands. The photos were produced using fish-eye hemispherical images. The images were "unrolled" so that the central pixel in the original image corresponds to the top line of the result, the circumference of the original image corresponds to the bottom line of the result (upper part of the figure). The upper parts of these photos look distorted but the unrolled images give a better visual impression of the stand than the original circular images.

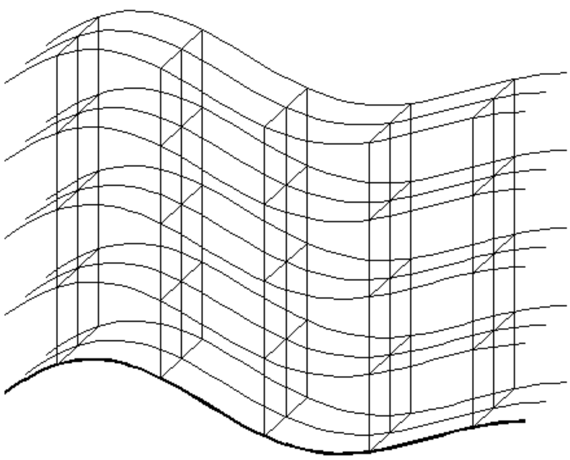

Figure 2: Voxels above ground

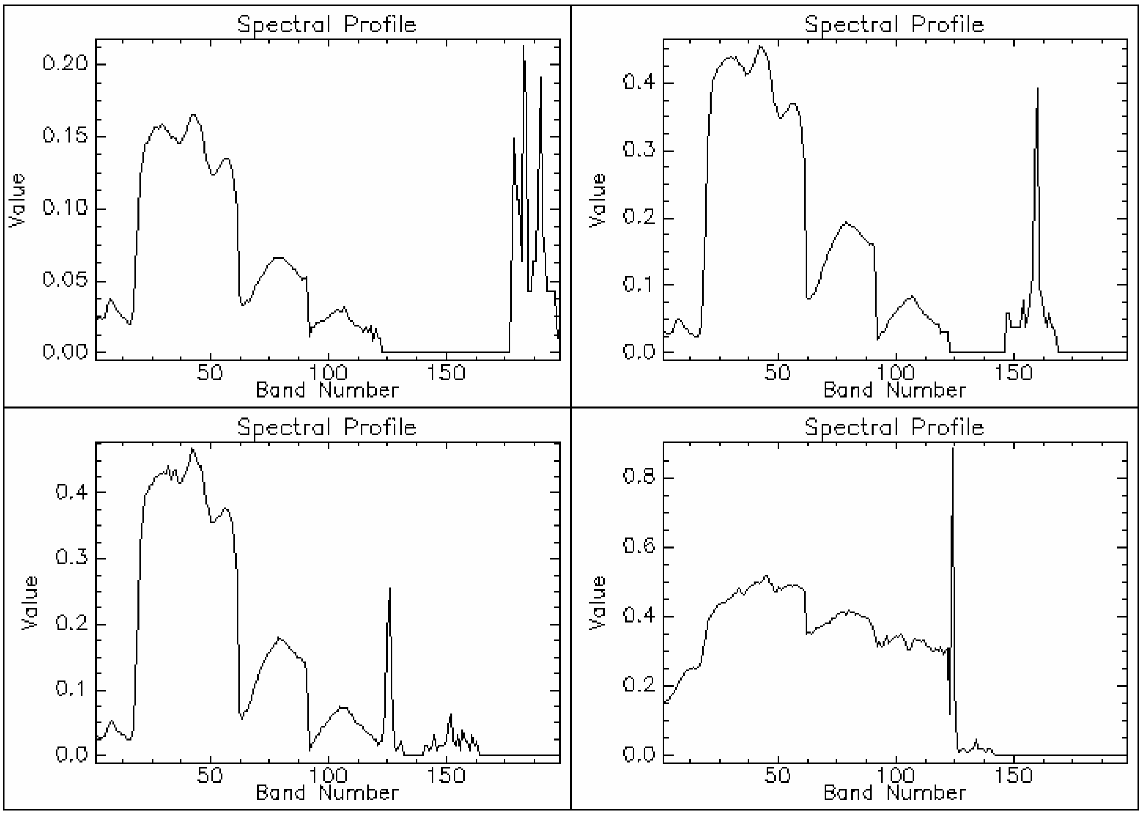

Figure 3: Combined hyperspectral and laserscanner data. Bands 1–122 contain the reflection from 440 to 2480 nm wavelengths. Bands 123–198 contain the mean laser intensity in a pixel. The upper left graph shows an old coniferous stand with high trees and no laser echo from the ground. The upper right graph shows a younger stand that is also too dense to allow a ground echo. The lower left graph a much less dense stand with a very clear ground echo. The lower right graph shows a forest track where nearly all of the laser echo comes from the ground.

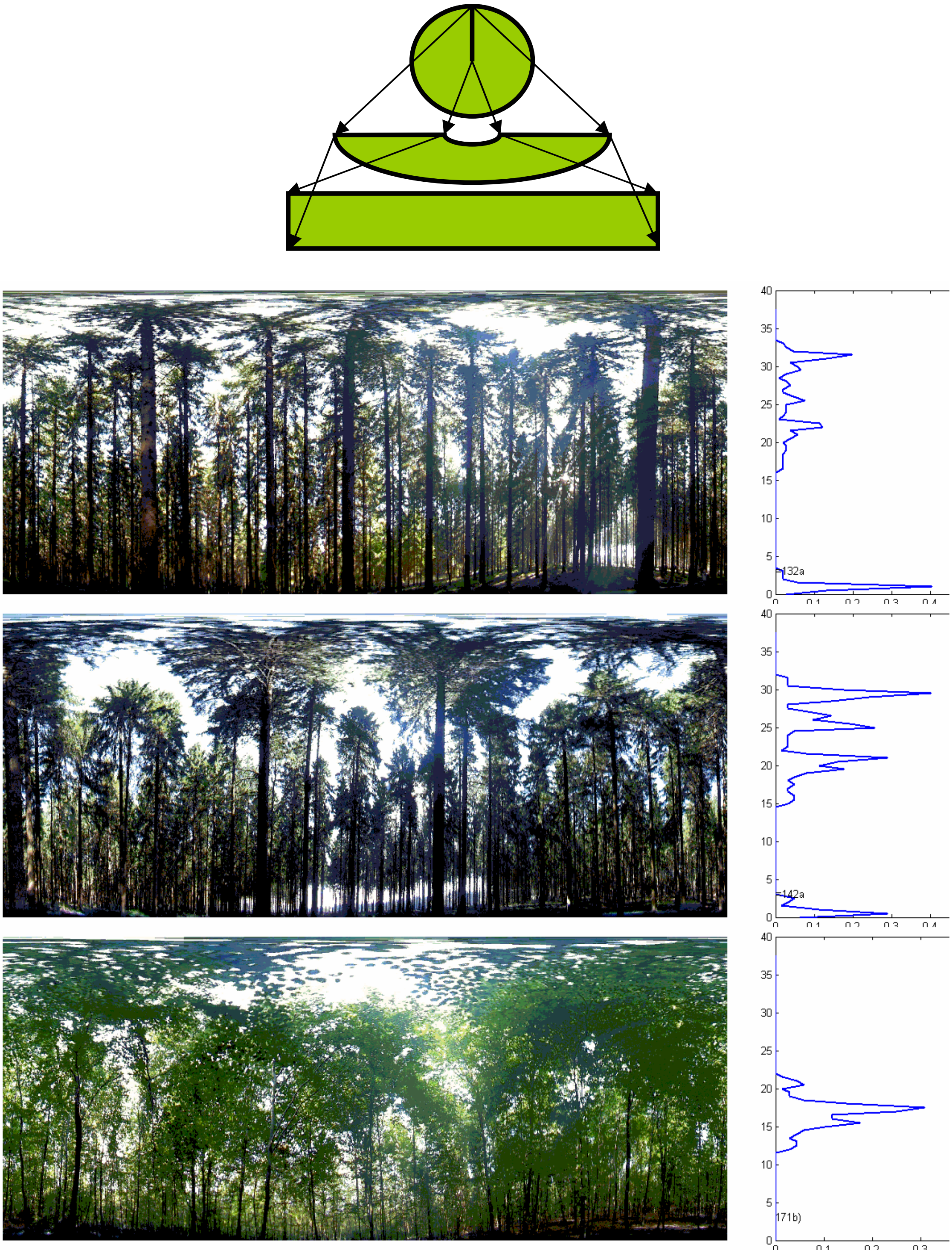

Figure 4: Unrolled hemispherical photos and corresponding ALS height profiles

3. Results and discussion

The results of this study are still preliminary. The combination of hyperspectral reflection data and airborne laser scanner full wave data is promising. The potential of characterizing the optical and structural features of forest stands by remote sensing is large and not yet fully exploited. While the discrimination of deciduous and coniferous trees works best using the reflection spectra, the discrimination between younger and older stands as well as the discrimination between dense and thinned stands can be better accomplished with ALS data. This can clearly be seen by an analysis of the hemispherical photos and their waveform spectra which serves as a visual validation.

Point clouds and tree height layers from first pulse or difference of first pulse and ground ALS data are a more compact means of characterizing stand age, but only the full wave data show the crown structure in a detailed way, especially if there are several layers of trees. Besides the stand age, which is mostly expressed in the tree heights, the ALS data shows the density of crowns. This might be used as a validation data set for a spectral mixture analysis of the hyperspectral data if vegetation and soil are unmixed.

A classification of the combined data set was tried but did not succeed due to numerical instability caused by the many zeros in the data set. When a SAM classification was carried out on a subset of the data, the overall accuracy was significantly raised when adding the ALS voxel data to the Hymap data. Instead of using the full dataset, a single channel containing the tree heights was combined with an MNF rotated version of the Hymap data (Green et al. 1988). With these data norway spruce and douglas fir stands were classified into four and two age classes, respectively, similar to the approach in Buddenbaum et al. (2004). The accuracy of a maximum likelihood classification was raised from 71.6 % using the Hymap data alone to 77.3 % (Kappa coefficient rose from 0.639 to 0.713). These promising results show further potential of the combination of classic remote sensing data with ALS data.

References

Buddenbaum, H., Schlerf, M. and Hill, J., 2005: Classification of coniferous tree species and age classes using hyperspectral data and geostatistical methods. *International Journal of Remote Sensing*, 26: 5453–5465.

Cocks, T., Jenssen, R., Stewart, A., Wilson, I., and Shields, T., 1998: The HyMap Airborne Hyperspectral Sensor: The System, Calibration and Performance. *1st EARSEL Workshop on Imaging Spectroscopy*, Zurich, October 1998.

Green, A.A., Berman, M., Switzer, P. and Craig, M. D., 1988: A Transformation for Ordering Multispectral Data in Terms of Image Quality with Implications for Noise Removal. *IEEE Transactions on Geoscience and Remote Sensing* 26 (1), 65–74.

Hopkinson, C., Chasmer, L. and Hall, R.J., 2008: The uncertainty in conifer plantation growth prediction from multi-temporal lidar datasets. *Remote Sensing of Environment*, 112: 1168–1180.

Holmgren, J., Nilsson, M. and Olsson, H., 2003: Simulating the effects of lidar scanning angle for estimation of mean tree height and canopy closure. *Canadian Journal of Remote Sensing*, 29 (5): 623–632.

Hug, C., Ullrich, A., and Grimm, A., 2004: Litemapper-5600 – A Waveform-digitizing Lidar terrain and vegetation mapping system. In: Thies, M., Koch, B., Spiecker, H. & Weinacker, H. (Hrsg.): *Proc. ISPRS Workshop 'Laser-Scanning for Forest and Landscape Assessment'*, Freiburg, Germany, 3-6 Oct 2004. ISPRS Archives Vol. XXXVI, Part 8/W2, 24–29.

Popescu, S.C., and Zhao, K., 2008: A voxel-based lidat method for estimating crown base height for deciduous and pine trees. *Remote Sensing of Environment*, 112: 767–781.

Schlerf, M., Atzberger, C., and Hill, J., 2005: Remote sensing of forest biophysical variables using HyMap imaging spectrometer data. *Remote Sensing of Environment*, 95: 177–194

Vane, G., and Goetz, A.F.H., 1988: Terrestrial Imaging Spectroscopy. *Remote Sensing of Environment* 24: 1-29.