SUMMARY OF THE SCANDLASER 2003 WORKSHOPS AND RECENT DEVELOPMENTS IN SWEDEN

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ABSTRACT:

Selected findings from the ScandLaser workshops held in Umeå, Sweden, September 2-4, 2003 are summarised together with recent Swedish studies related to laser scanning of forests. By use of correlative methods, such as regression analysis between laser data features and field measured forest variables, promising results have been achieved in a large number of tests in Scandinavian coniferous forests. The results are consistent for different test sites, sensors and estimation methods. Typical accuracies (RMSE), when aggregated to stand level are: for stem volume 11 – 19%; Lorey's mean height 3 – 6%; and mean stem diameter 6 – 12%. Plot and stand level analysis methods are not partcularly sensitive to scanning density. With more dense scanning (several pulses per tree) and single tree methods, more than 70% of the trees can be detected, and the tree height and diameter can be measured with about 0.6 m RMSE. By combining data from two time points, detection of the harvesting of single trees, and measurement of tree growth, have been demonstrated in Finland. By combining laser data and optical data, Norway spruce, Scots pine and deciduous trees have been discriminated with 90% overall accuracy in Swedish tests. Stand-wise inventory where laser data and photo interpretation are used in combination is now marketed as operational in Norway. The results achieved with laser scanning are better than with other sensors and a future operational breakthrough for laser scanning aided forest inventory is very likely. However, this is not likely to happen until cost efficient solutions are found. The rapid technical development, especially on the military side, will contribute to more compact sensors with high spatial resolution. Large-area sampling might be one area where laser scanning is already motivated today.

1. INTRODUCTION

In May 2002, a group of researchers from Sweden, Norway, Finland and Canada met informally to discuss recent experiences with laser scanning for forestry applications. Plans were then made to follow up with a more formal meeting with wider participation, which eventually became ScandLaser 2003. To the knowledge of the organisers, ScandLaser was the first international meeting of its kind in Europe, and several of the participants met for the first time. During 2002, two similar meetings had been held in Australia and Canada: "The Australian Workshop on Airborne Laser Altimetry for Forest and Woodland Inventory and Monitoring"held in Brisbane; and the "Workshop on Three-Dimensional Analysis of Forest Structure and Terrain Using Lidar Technology", held in Victoria, British Columbia. Key papers from those two workshops are published in a special issue of Canadian Journal of Remote Sensing (volume 29, no 5, 2003). A summary is also given in the ScandLaser Proceedings (Wulder, 2003). NatScan can partly be viewed as a continuation of these three meetings.

ScandLaser was held September 2-4, 2003 in Umeå, Sweden, and attracted about 80 participants from 16 different countries. The first day was a "Practical Workshop" which was intended to present the current operational capabilities of laser scanning technology for the end-user community. The highlight was a method for standwise forest inventory based on laser scanning which has been developed by Professor Erik Næsset at the Agricultural University of Norway and is now marketed as operational by the Norwegian company Prevista AS. This was followed by a two day scientific workshop, where 33 papers were presented. Of these, 27 papers addressed measurements of forests with airborne laser scanners, one contribution addressed the use of data from satellite-borne lasers, and 5 papers presented as posters focussed on terrestrial laser scanning. The scientific papers presented at ScandLaser are available in a proceedings volume (Hyyppä, et al., 2003a). In addition, a subset of the papers has been peer reviewed, and will be published in a special issue of Scandinavian Journal of Forest Research, which is expected to appear late 2004.

The aim of the present contribution to NatScan is to summarise some common themes and findings presented at ScandLaser in the field of airborne laser measurements of forest resources and to indicate the road towards more widespread operational applications. This review has an emphasis on applications in Scandinavia and is complemented and updated with results from studies made in Sweden during 2004 as well as some other important references, For a more complete bibliography, please consult the one maintained University of Zürich at: http://www.geo.unizh.ch/rsl/services/bibliographies/lidar/ and for a more general review, se for example Lefsky et al. (2002).

2. THE EARLY DEVELOPMENT IN SWEDEN, FINLAND AND NORWAY

Despite the similarities between the countries, forestry laser scanning research has until now developed quite independently in Sweden, Norway and Finland. This development was summarized at ScandLaser in three "country reports" (Nilsson et al., 2003; Hyyppä et al., 2003b; and Næsset, 2003).

The development in Sweden started in the mid 1980's with FLASH, which was a military full waveform laser scanning system for naval surveillance (Steinvall 2003). Mats Nilsson from the Swedish University of Agricultural Sciences (SLU) was given the opportunity to test this system for the purpose of forest parameter retrieval on three different occasions during 1991 (Nilsson, 1996). It was concluded that laser scanning had a potential for retrieval of stem volume using regression functions based on laser data features and field plot measurements. Different beam sizes, from 0.75 – 3.0 m footprint diameter were tested, without any consistent differences in the result. One problem with this early study was however that the system lacked precise positioning with INS or GPS. The experiences from FLASH system inspired the company SAAB to build the helicopter borne TopEye, which is a very flexible laser scanner system, well suited for research. TopEye has been used in six forestry related laser scanning campaigns in Sweden between 1997 and 2003 (Nilsson et al., 2003).

The development in Finland started in the mid 1990's by Juha Hyyppä and also with a meeting arranged by FM-Kartta Oy in 1997. Finnish researchers and companies have been very active in the development of methods for creation of DTM´s in forested landscapes, and also in the development of single tree based inventory methods (Hyyppä et al., 2003). The studies have been carried out mainly with data from TopoSys 1 and TopSys Falcon, but also with data from the TopEye system.

The development in Norway started 1995 when Erik Næsset made a test together with the aerial survey company FotoNor. Mean height and stem volume were successfully estimated on stand level for 36 stands (Næsset 1997a; Næsset 1997b). All tests in Norway have been done with Optech ALTM and currently there is a 33 000 Hz ALTM 2033 operating from Norway.

3. LASER SCANNING OF FOREST RESOURCES

3.1 Ecological applications

Since the remaining parts of this paper are concentrated on retrieval of forest inventory parameters, it is worth pointing out that laser scanning data is also becoming an important data source for ecological models. At ScandLaser, Hill (Hill et al., 2003) presented how vegetation height information from laser scanner data could be used for bird habitat modelling and Sato (Sato et al., 2003) presented how a laser derived DTM was used for research about wood mice habitat. Such ecological applications might become realistic since large areas of many countries now are being laser scanned for the purpose of creating improved digital terrain models.

3.2 Large area sampling

Since laser scanning is an accurate method but expensive per area unit, one promising application is in large area sampling where a total coverage not is needed and where the laser data can be combined with an even sparser field sample. Such sampling has been tested in Australia (Wulder, 2003). At ScandLaser Nelson (Nelson et al., 2003) showed how data from an inexpensive profiling lidar, flown with strips 4 km apart, had been used for estimating the forest resources in the whole state of Delaware. Sweda et al. (2003) showed how a 600 km long transect in western Canada, flown with a laser profiler in 1997 and again with a laser scanner in 2002, had been used for estimation of forest changes. These studies can be seen as pilots for future large area assessments, e.g. for assessing changes in forest carbon.

3.3 Single tree detection

Several groups have developed processing algorithms for detection and measurement of individual trees from high density laser scanner data. Examples presented at ScandLaser include work from the UK (Suarez et al., 2003) and from Freiburg (Diedershagen et al., 2003) who both had aggregated the tree level analysis to stand level. Tomas Brandtberg from Sweden has developed a system for single tree detection, based on scale-space theory (Brandtberg et al., 2003a; 2003b). Popescu et al. (2003) estimated crown diameters with a RMSE of 1.4 m for both deciduous and pine in south eastern USA. The Swedish Defence Research Agency (FOI) has in co-operation with SLU developed and validated a system for single tree detection. Using laser data with a density of 5 pulses / m^2, about 70% of the trees in coniferous forest in a test site in southern Sweden were detected, and tree heights and crown diameters were estimated with an accuracy of 0.6 m (Persson, et al., 2002). Using laser scanner data only, discrimination between spruce and pine could be made with an accuracy of 95% (Holmgren and Persson, 2004). By using the laser scanner data for tree segmentation only and optical data from the Z/I DMC digital camera for tree species discrimination, spruce, pine and deciduous trees could be discriminated with 90% overall accuracy (Persson et al., 2004). Earlier attempts to estimate tree species proportions on stand level, using laser scanner data have been less successful (Törmä, 2000), thus, the need for tree species discrimination might be one motivation for aiming at single tree methods.

In Finland, single tree detection based on laser scanner data was first reported by Hyyppä and Inkinen (1999) and was implemented in commercial software already in 2000. Tree species (pine, spruce and deciduous) have been discriminated with accuracies between 66% and 79%, and tree heights have been estimated with an accuracy of about 0.5 m (Hyyppä et al., 2003b). In a multi-temporal analysis, it was shown that all harvested dominant trees could be detected, and that 2 years of forest growth could be estimated with a precision of 0.05 m on stand level and 0.15 m on plot level (Yu et al., 2004).

3.4 Estimates on plot and stand level

On sample plot level, a number of forest variables from field measured and GPS positioned plots can be predicted from features derived from laser data..Regression functions fit with measured plot data could then be applied across a raster grid of laser features for full coverage.. Stand level estimates could be obtained by averaging the grid cell estimates within a stand. Alternatively, it is also possible to regress summary forestry statistics for a stand against the laser data features aggregated to stand level, and apply this relationship to other stands (Fransson, 2004). Plot and stand level estimates could also gain from including laser derived features extracted at single tree level. For example, Popescu et al. (2003) showed that the inclusion of lidar derived crown diameter improved stem volume and biomass estimates. However, Holmgren et al. (2003), observed worse plot level results, when data from a simple tree-counting algorithm was included.

The framework developed in Norway and now commercially marketed (Næsset and Bjerkenes, 2001; Næsset 2002, 2003), is based on stepwise regression, where a large number laser derived height percentiles and density measures within grid cells are regressed against field plot measured forest features. Similar procedures have also been tested in Sweden with similar results (Holmgren 2004a, 2004b), (Table 1). Good correspondence between laser data and stem volumes in coniferous forest was also reported during ScandLaser from tests in the Netherlands (Clement et al., 2003) and Russia (Alekseev et al., 2003).

Study	Variable	Plot level precision or accuracy SD or RMSE (%)	Stand level precision or accuracy SD or RMSE (%)
Næsset (2002)	Mean height Mean diam. Stem volume	6.1-6.7 % SD 12-14 % SD 15-24 % SD	3.7-6.3 % SD 6.5-12 % SD 11-14 % SD
Holmgren et al. (2003)	Mean height Stem volume	10 % RMSE 22 % RMSE	
Holmgren (2004a)	Mean height Stem volume	5.6 % RMSE 20 % RMSE	3.1 % RMSE 11-19 % RMSE
Holmgren (2004b)	Mean height Mean diam. Stem volume		4,2 % RMSE 8.1 % RMSE 11 % RMSE
Fransson et al. (2004)	Stem volume		12 % RMSE
Maltamo et al. (2004)	Stem volume Stem number	16 % RMSE 49 % RMSE	

Table 1. Scandinavian examples of forest variable accuracies achieved with laser scanner data at plot level and stand level. Mean height = Lorey's mean height. Mean diam. = basal area weighted mean stem diameter at breast height.

The accuracy reported in Table 1 for stand level stem volume estimates is in the same range, or better, than the traditional manual methods applied in Sweden. According to Ståhl (1992), the stand level accuracy for traditional field surveys using a few subjectively located relascope measurements per stand, is in the order of 20%, whereas about 15% accuracy can be achieved by interpretation and measurement of air photos in photogrammetric instruments. Differences in stand composition, estimation procedures, and in evaluation procedures, make it however difficult to compare results between inventories. Studies where different methods have been validated with the same field material are therefore especially valuable. In one such study, Hyyppä et al. (2000) obtained the best stand level accuracy for stem volume (13.5%) for laser scanner data, this was followed in order by the AISA imaging spectrometer, SPOT XS, and last SPOT Panchromatic with 49.6%. In a study by Fransson et al. (2004), the best stand level stem volume accuracy was also obtained with laser scanner data (12%), followed by 17% for the combination of multispectral SPOT 5 data and laser data, and 31% for only multispectral SPOT 5 data.

Several systems for forecasting of forest growth need data about diameter distribution of single trees, and not only stand mean values. In an ongoing study, carried out by Jörgen Wallerman at SLU, imputation methods, such as k-Nearest Neighbour, are being studied. Stem diameter information from field plots is moved to unmeasured stands, using sensor data as "carrier data". In the study by Wallerman, laser data alone performed better than the combination of laser data and multispectal SPOT 5 data, and SPOT 5 data alone performed worst. Maltamo et al. (2004) fitted Weibull-distributions to calibrated tree heights obtained from tree segments in laser data, thus generating both stem volume estimates and diameter distributions with a minimum of field data. Gobakken and Naesset (2003) used empirical regression function to relate a system of 10% percentiles of the diameter distribution to laser data features.

4. METHODOLOGICAL ISSUES AND ERROR SOURCES

The consistently good results obtained with different small footprint pulsed laser systems indicates that the choice of system not is critical for the accuracy. Neither have methods that are based on plot or stand level laser features been especially sensitive to decreased posting density (Næsset 2003). When Holmgren (2004a), decreased the posting density from 4,3 pulses / m^2 to 0,1 pulses / m^2 the, error for stand level stem volume estimates only increased from 19% to 21%.

Several factors influence the DTM and the measured canopy height, examples are: flying altitude and scan angle (Hyyppä, 2003) step slopes, and also trees that don't grow vertically on slopes (Heurich et al., 2003). The height measured by laser scanner is often an underestimate (Nilsson 1996; Maltamo et al., 2004). Heurich et al. (2003) showed with field measurements of 750 trees in Bavaria, that the average underestimation of tree height with laser DSM was 0.37 m for deciduous trees and 1.14 m for coniferous trees. However, they also conclude that apart from the systematic under estimation, the laser measured heights are at least as precise as the field measured heights. It can be assumed that a certain penetration of the laser beam into the canopy is needed, before enough photons are reflected back (Gaveau and Hill, 2003). Furthermore, the ground vegetation might reflect back the signal a bit over the ground. Böttcher and Kleinn (2003) showed how the choice of different processing methods changed the laser measured heights by more than 2m. The easiest way around all these uncertainties is to relate the laser signal to field measured ground truth plots and correct for any bias. That approach will also allow other forestry variables to be estimated than those directly measured by the laser. Furthermore, since the laser data is correlated with the LAI (Riaño et al., 2004), and most likely influenced by the LAI, which is a factor that varies over the vegetation season, it will until otherwise proven, be safest to use field plots that are scanned on the same day as the area to be estimated.

The results for mixed deciduous – coniferous, and deciduous forests are less promising than for the pure coniferous forest (Næsset, 2003). Dense temperate deciduous forests appear to be even more difficult than boreal deciduous forests. Brandtberg et al. (2003b) applied the same single tree detection scheme to coniferous forest in southern Sweden and temperate deciduous forest in southern USA during leaf off conditions. They conclude that improved single tree detection methods would be need for the latter case. Heurich et al. (2003) showed that the accuracy of derived DTM, during various Bavarian conditions, were better for early spring (leaf off), than for summer conditions (leaf on). Also Hirata et al. (2003), stress the importance of using data from the leaf-off season in temperate deciduous forest. They found that the transmittance through the canopy was 69% during leaf-off season, compared to 20% for the leaf-on season.

5. TECNICAL DEVELOPMENT

Civilian systems, designed primarily for terrain mapping, are still getting higher pulse rates, (presently up to about 100 000 Hz), and are being designed for higher flying altitudes. There is also an increasing degree of integration between the laser systems and digital mapping cameras. This will enable laser scanners and digital cameras to be a standard configuration onboard surveying aircrafts. Such aircrafts will thus also be a resource for large area forest inventories.

An example of the rapid technical development is that TopEye in Sweden now is testing a new own laser scanner This system has high pulse rate, cm accuracy, and looks both forward and backward along the flight line.

However, the most revolutionary technical breakthroughs will come from the military side. The strong development in military laser radar technology was made clear at ScandLaser by Ove Steinvall from the Swedish Defence Research Agency (Steinvall, 2003). Among the many powerful technologies under development in military labs and already being implemented, Dr Steinvall especially pointed out that 3D Focal Point Array's is about to revolutionise laser measuring technology. With FPA technology, it will be possible to capture a distance image directly from one laser pulse. This will give compact sensors with very high resolution and a minimum of moving parts. Dr Steinvall also points out the possibilities for vegetation surveys, offered by multi-wavelength lasers and flouroscence. The military needs will also speed up the developments towards using small, automatically navigated, un-manned aircrafts (UAV's) as sensor carriers.

6. CONCLUSIONS AND THE ROAD TOWARDS OPERATIONAL APPLICATIONS

In many countries, large areas are currently being laser surveyed for creation of new DTM's. In such cases, the laser data could as a spin-off, also be used for providing overviews of forest resources, and for ecological models. Laser scanning on a sampling basis for large-area estimates, for example changes in carbon stock, is probably also a realistic alternative in the cases were new inventory designs are discussed. But how about using laser scanning for ordinary standwise forest mapping? Ward Carson, University of Seattle (Carson et al., 2004), sent out a worldwide questionnaire about this. He concludes that forest companies are happy with their current inventory procedures, until a more cost efficient method is available. The only operational application he found was the one being marketed in Norway.

The Norwegian method is still more expensive than photogrammetric methods, but is motivated by its advocates with the higher data quality, which by use of forest economic models could be shown to pay off. It is interesting to note that several positive factors are in place in Norway that contribute to the successful application of laser based forest inventory: a coniferous dominated landscape; researchers working with laser scanning of forest resources; a private surveying company owning a modern laser scanner; a forest mapping company that works with modern technology; and the presence of state subsidies when large forest mapping efforts are co-ordinated between many land owners.

In Sweden, the largest forestry laser scanner project so far was for a 5000 ha area in the county of Dalarna. The project was ordered by the regional forestry board and the purpose was to investigating the feasibility of the technology when revising real-estate boundaries for forest estates (Holmgren and Jonsson, 2004). The prime need for stand wise laser scanner aided mapping in Sweden is most likely for management planning among a few large forest companies that together own about 9 million ha of productive forest land. The other half of the forest land is owned by thousands of small forest owners, who usually not co-ordinate their forest inventory activities, and special flights could with present technology not be motivated for small individual estates.

My own expectations are that more automated procedures and lower flying cost when laser and digital camera are operated together, will in the near future make laser scanning a cost competitive method for large area forest mapping. Thus, there is a need for research related to practical procedures for such inventories and the associated data processing. The expected revolution in sensor technology also motivates more basic related to single tree methods, and to the physics of forestry laser scanning. Such research could also help in the constructing of dedicated sensors for the forest inventory purposes.

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