Nordic Forest Research
Cooperation Committee - SNS

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Project number: 103

FINAL PROJECT REPORT

Please notice that the size of text sections in the form can be adjusted if needed.
The length of the final report should not exceed 5 pages.

1. Projekt titel	Ny teknologi för förbättrad information om virkesresurser–utveckling av ett integrerat informationssystem (IRIS)
2. Title of project	New Technologies to Optimize the Wood Information Basis for Forest Industries - Developing an Integrated Resource Information System (IRIS)
3. Project leader /coordinator (name, address, telephone, telefax. e-mail)	Dr Johan Holmgren Department of Forest Resource Management SLU SE 901 83, Umeå, Sverige. Telefon: +46 90 7868602 Telefax: +46 90 778116 e-mail: johan.holmgren@slu.se
4. Time schedule	The project started 01.01.2008 and ended 31.12.2010
5. Project cost	SNS-grant: 150 000 EUR Total project cost: 1223 381 EUR
6. The purpose of the project/main problems/hypotheses addressed	1) Development and optimization of laser scanner methods for assessment of wood qualities and quantities at high spatial resolution and validation of these methods across countries. 2) Further improvement of the information flow regarding wood resources along the forest/wood-products chain by adapting forest information and planning systems to utilize improved information from laser scanner aided inventories.
7. Brief description of the research plan and of possible larger deviations from the plan	Methods were developed to: extracts quality-related properties of single-trees; combining low and high density data; improve tropical plantation inventory procedures; utilize a XML based information system; optimize silvicultural treatments; estimate tree lists; predict product recovery from pre-harvest inventories with airborne laser scanning data trained by ground-based laser scanning or harvester data; utilising single tree data in tactical forest management planning. Also, comparative testing was done of algorithms for single-tree detection and feature extraction.

8. Results (max 2 pages)	The 3D structural information of the forest derived from airborne laser scanner (ALS) data can be used to detect and measure trees. Several teams within the project worked on the development of algorithms for segmentation of individual trees. These algorithms were evaluated on data sets from different participating countries in a joint work package (Vauhkonen et al. 2010b). However, not all trees in the forest can be detected, even with the most advanced algorithms. Therefore, methods were developed that account for segmentation errors and resulted in model-unbiased estimates (Lindberg et al. 2010a; Breidenbach et al. 2010a). The simultaneous use of high and low resolution ALS data allowed a reduction of field work when combined with semi-supervised methods (Breidenbach et al. under preparation). Methods for the classification of tree species as such (Ørka et al. 2009) or the prediction of tree species-specific variables such as canopy base height (Breidenbach et al. 2010e, Vauhkonen 2010a, Breidenbach et al. submitted) and timber volume (Breidenbach et al. 2010b) were developed in several work packages. The possibilities to efficiently obtain wood quality related variables using existing manual field methods are limited. Therefore, methods for the estimation of stem attributes using terrestrial laser scanning (TLS) by measuring the diameter for all visible stem parts have been developed. A complete method for combining TLS measurements of tree stems and crown segments from ALS data for estimations of stem diameters was compared with conventional methods (Lindgren et al. 2008; Lindgren et al. 2010b). This included the automatic linking of ALS and TLS data at an individual tree level (Olofsson et al. 2008). The stem measurements obtained from TLS were also compared with measurements from harvesters. Harvester data were imputed to areas without reference data using ALS-derived crown segments. The prediction results of stem mean tree height, and stem diameter distributions were validated at sub-stand level (Holmgren et al. 2010). A new ALS based forest inventory and planning concept was developed for industrial eucalyptus plantations in Brazil. The use of dynamic treatment units in forest planning could be used in the future also in the Nordic countries to make more optimal decision about which areas that will be harvested. Spatially optimized cutting areas often deviated from compartment boundaries (Packalén et al. submitted). Stand attributes and site index were modeled by Zonate et al. (2010) and Packalén et al. (submitted). The accuracies were considerably better than what is typically attainable in boreal forests. In industrial plantations it was also possible to utilize clone information in the statistical models. With respect to stem volume, clone information improved the accuracy over 30%. Additionally, a theoretical model for ALS based forest inventories was developed and validated on data from Brazilian eucalyptus plantations (Mehtätalo et al. submitted). Forest information systems were therefore developed and improved to enhance the information flow within the forest enterprises. To go one step further and provide this information to the end users, e.g., the wood processing industry, a software prototype was developed that includes a logistics interface. In the interface the users can select the forests that best meet industry demands by assigning specific log demands to each forest. The web based platform also allows an efficient means to transfer information throughout an organization. A XML-based forest plantation simulator was developed to model the wood flow

	(Seppänen et al. under preparation). The simulator was also used as a benchmarking system for actual harvests in Brazilian eucalyptus plantations. The digital road network, digital elevation models, and tree data need to be utilized in planning of harvesting operations. A co-operation with the University of Lavras (Brazil) was established to fulfill this task. Field data were collected from forest roads and methods for predicting the road quality using ALS data were developed.
9. What advantages has been gained by the Nordic collaboration (i.e. by the cooperating partners, use of the project results)	The forest industry in all Nordic countries has started to use the laser scanning technology for forest inventory and planning. However, new methods are needed to utilize the new technology. The project has supported research in each country with close connection to the industry and has promoted a network of researchers in the interface between remote sensing and planning.
10. Publications and other communication activities (please list scientific reports, more popular reports and other communication activities)	**Articles in international scientific journals with peer review** *Breidenbach, J, Næsset, E, Lien, V, Gobakken, T, Solberg, S (2010a). Prediction of species specific forest inventory attributes using a nonparametric semi-individual tree crown approach based on fused airborne laser scanning and multispectral data. Remote Sensing of Environment, 114(4), 911-924, doi: 10.1016/j.rse.2009.12.004.* *Breidenbach, J, Nothdurft, A, Kändler, G (2010b). Comparison of nearest neighbour approaches for small area estimation of tree species-specific forest inventory attributes in central Europe using airborne laser scanner data. European Journal of Forest Research, 129(5), 833-846, doi: 10.1007/s10342-010-0384-1.* *Breidenbach, J, Ortiz, S, Reich, M (2010c). Forest monitoring with TerraSAR-X: first results. European Journal of Forest Research, 129(5), 813-823, doi: 10.1007/s10342-009-0318-y.* *Breidenbach, J, Næsset, E, Gobakken, T, Solberg, S, Lien, V (submitted). Using airborne laser scanning, multispectral data and segmented tree crowns for an inventory of variables related to timber quality. Remote Sensing of Environment.* *Breidenbach, J, Næsset, E, Gobakken, T, Lien, V (under preparation). Synergetic use of high and low density ALS data in forest inventories - a model-based approach.* *Hawbaker, T, Gobakken, T, Lesak, A, Tromborg, E, Contrucci, K, Radeloff, V (2010). Light Detection and Ranging-Based Measures of Mixed Hardwood Forest Structure. Forest Science, 56(3), 313-326.* *Korpela, I, Ørka, H, Maltamo, M, Tokola, T, Hyyppä, J (2010). Tree species classification using airborne lidar–effects of stand and tree parameters, downsizing of training set, intensity normalization, and sensor type. Silva Fennica, 44(2), 319-339.* *Lindberg, E, Holmgren, J, Olofsson, K, Wallerman, J, and Olsson, H (2010). Estimation of tree lists from airborne laser scanning by combining single-tree and area-based methods. International Journal of Remote Sensing, 31, 1175 - 1192.* *Magnussen, S, Næsset, E, Gobakken, T (2010). Reliability of LiDAR derived predictors of forest inventory attributes: A case study with Norway spruce. Remote Sensing of Environment, 114(4), 700-712.*

	Mehtätalo, L, Nyblom, J (submitted). A model-based approach for ALS inventory: application for square grid spatial pattern. Forest Science. *Packalén, P, Heinonen, T, Vauhkonen, J, Pukkala, T, Maltamo, M. (2011) Dynamic Treatment Units in Eucalyptus Plantation. Forest Science* *Packalén, P, Mehtätalo, L, Maltamo, M. (2011) ALS based estimation of plot volume and site index in a Eucalyptus plantation with a nonlinear mixed effect model that accounts for the clone effect. Annals of Forest Science.* *Salas, C, Ene, L, Gregoire, T, Næsset, E, Gobakken, T (2010). Modelling tree diameter from airborne laser scanning derived variables: a comparison of spatial statistical models. Remote Sensing of Environment, 114(6), 1277-1285.* *Seppänen, A, Eerikäinen, K, Tokola, T (under preparation). Using synthetic data and Monte Carlo simulation in the evaluation of forest growth and yield simulators designed for Pinus kesya plantations in southeastern Africa.* *Vauhkonen, J, Tokola, T, Maltamo, M, Packalén, P (2008). Effects of pulse density on predicting characteristics of individual trees of Scandinavian commercial species using alpha shape metrics based on airborne laser scanning data. Canadian Journal of Remote Sensing, 34, 441-459.* *Vauhkonen, J, Tokola, T, Packalén, P, Maltamo, M (2009). Identification of Scandinavian commercial species of individual trees from airborne laser scanning data using alpha shape metrics. Forest Science, 55(1), 37-47.* *Vauhkonen, J, Korpela, I, Maltamo, M, Tokola, T (2010). Imputation of single-tree attributes using airborne laser scanning-based height, intensity, and alpha shape metrics. Remote Sensing of Environment, 114(6), 1263-1276, doi: 10.1016/j.rse.2010.01.016* *Vauhkonen, J (2010). Estimating crown base height for Scots pine by means of the 3-D geometry of airborne laser scanning data. International Journal of Remote Sensing, 31(5), 1213-1226, doi: 10.1080/01431160903380615* *Vauhkonen, J., Mehtätalo, L. and Packalén, P. (2011). Combining tree height samples produced by airborne laser scanning and stand management records to estimate plot volume in Eucalyptus plantations. Canadian Journal of Forest Research 41:(8) 1649-1658.* *Zonete, MF, Rodriguez, LCE, Packalén, P (2010). Estimação de parâmetros biométricos de plantios clonais de eucalipto no sul da Bahia: uma aplicação da tecnologia laser aerotransportada. Scientia Forestalis, 86, 225-235* *Ørka, HO, Næsset, E, Bollandsås, OM (2009). Classifying species of individual trees by intensity and structure features derived from airborne laser scanner data. Remote Sensing of Environment, 113(6), 1163-1174.* **Other scientific publications** *Lindberg, E, Holmgren, J, Olofsson, K, Olsson, H, Wallerman, J (2008). Estimation of tree lists from airborne laser scanning data using a combination of analysis on single tree and raster cell level. Proceedings of the SilviLaser conference 2008, Edinburgh, Great Brittan, Sept. 17-19, 2008.* *Maltamo, M, Bollandsås, OM, Næsset, E, Gobakken, T, Packalén, P (2009). Different sampling strategies for field training plots in ALS inventory. Proceedings of the SilviLaser conference 2009, College Station, USA, Oct. 14-16, 2009.* *Olofsson, K, Lindberg, E, Holmgren, J (2008). A method for linking field-surveyed and aerial-detected single trees using cross correlation of position images and the optimization of weighted tree list graphs. Proceedings of the*

	SilviLaser conference 2008, Edinburgh, Great Brittan, Sept. 17-19, 2008. *Ørka, HO, Næsset, E, Bollandsas, OM (2009). Comparing classification strategies for tree species recognition using airborne laser scanner data. Proceedings of the SilviLaser conference 2009. College Station, Texas A&M University.* *Breidenbach, J, Kublin, E (2009). Estimating Timber Volume using Airborne Laser Scanning Data based on Bayesian Methods. Proceedings of the IUFRO Division 4 conference Extending Forest Inventories over Space and Time. Quebec City, Canada, May 19-22, 2009.* *Breidenbach, J, Næsset, E, Gobakken, T (2010d). Model-based variance estimation for aggregated predictions of forest attributes to stand level based on airborne laser scanning data. Proceedings of the SilviLaser conference 2010, Freiburg, Germany, Sept. 14-17, 2010.* *Breidenbach, J, Næsset, E, Lien, V, Gobakken, T, Solberg, S (2010e). Towards an inventory of quality attributes of individual trees using airborne laser scanning and multispectral data. Proceedings of the SilviLaser conference 2010, Freiburg, Germany, Sept. 14-17, 2010.* *Holmgren, J, Barth, A, Larsson, H, Olsson, H (2010). Prediction of stem attributes by combining airborne laser scanning and measurements from harvesting machinery. Proceedings of the SilviLaser conference 2010, Freiburg, Germany, Sept. 14-17, 2010.* *Lien, V, Breidenbach, J, Næsset, E, Gobakken, T (2010). Assessing laser pulse penetration in spruce canopies - combining field measured branch properties with discrete return airborne laser scanning data. Proceedings of the SilviLaser conference 2010, Freiburg, Germany, Sept. 14-17, 2010.* *Lindberg, E, Holmgren, J, Olofsson, K, Olsson, H (2010b). Estimation of stem attributes using a combination of terrestrial and airborne laser scanning. Proceedings of the SilviLaser conference 2010, Freiburg, Germany, Sept. 14-17, 2010.*
11. Project summary (about 1/3 page) with main emphasis on results for possible use in the News & Views section of Scandinavian Journal of Forest Research	The aim of the project was to develop methods that benefit from emerging and rapidly evolving sensor and information technologies, primarily laser scanning. These methods provide timely and accurate information about wood properties of forests. Methods were developed for automatic measurements of trees using airborne laser scanning combined with manual field inventories, ground based laser scanning, or data collected by harvesters. However, not all trees in the forest can be detected. Therefore, methods were developed that account for not detected trees and produce model-unbiased estimates. A new forest inventory and planning concept was developed using dynamic treatment units to optimize the allocation of harvesting operations. Forest information systems were developed and improved to enhance the information flow within the forest enterprises. To go one step further and provide this information to the end users, e.g., the wood processing industry, a software prototype was also developed that includes a logistics interface.
12. Date and signature	Date: 2/9-2011 Signature of project leader/coordinator