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Nordic Forest Research (SNS)

Accurate 3D and 4D tree and forest models from point cloud data.

prof. Mikko Kaasalainen, Tampere Technical University

Abstract

Laser scanning techniques have brought about the possibility to model trees and forests efficiently from point clouds in 3D detail. These quantitative structure models (QSMs) contain any desired geometric, volumetric, and topological properties of trees (Raumonen et al. 2013, Rem. Sens. 5, 491; sample models can be interactively viewed at http://math.tut.fi/inversegroup/treegallery). QSMs allow fast practical computations; for instance, stem and branch diameters, lengths, tapering, direction angles (or curves), and structure or biomass statistics are obtained automatically (Liski et al. 2014, Global Change Biol. Bioen. 6, 777; Calders et al. 2015, Meth. Ecol. Evol. 6, 198). Time series measurements also allow detailed change detection (S. Kaasalainen et al. 2014, Rem. Sens. 6, 3906).

With the advent of lightweight and mobile scanners, this approach allows for the first time the fast and precise 3D mapping of large forest areas (Raumonen et al. 2015, ISPRS Annals, II-3W4, 189). Such models can be used for a wide variety of ecological studies and inventory applications, especially since tree species can be automatically identified from QSMs (Åkerblom et al. 2017, Rem. Sens. Env. 191, 1). The scheme has been expanded to 4D growth models by modifying theoretical plant growth algorithms to have stochastic components that produce the characteristic structural properties for each species (Potapov et al. 2016, Silva Fenn. 50, 1413). In addition, QSMs can be augmented by realistic foliage in a desired manner by either geometric primitives (for visualization and ray-tracing) or volume distributions (for fast computation of lighting properties, leaf biomass, etc.).

The measurements are made by a large international collaboration network that also develops new types of instruments (see TLS International Interest Group, http://tlsiig.bu.edu), such as the multispectral lidar that allows the identification of the surface material (chlorophyll, moisture, the condition of the tree, etc.) in addition to the laser scanning point cloud (Hakala et al. 2015, Biogeosci. 12, 1629; http://salca-salford.blogspot.com). The combination of new methods and instrumentation allows the modelling of forests with unprecedented detail and quality.

Terrestrial laser scanning for forest inventories - Influence of laser beam diameter on DBH retrieval

Meinrad Abegg[1] meinrad.abegg@wsl.ch (Presenting Author)

Felix Morsdorf[2] felix.morsdorf@geo.uzh.ch

[1)]Forest Resources and Management, WSL Swiss Federal Institute for Forest, Snow and Landscape Research

[2)]Remote Sensing Laboratories, Department of Geography, University of Zurich

Abstract

In the recent years, portable laser scanning devices and their applications for forest inventory show a rapid development. Even though terrestrial laser scanning (TLS) technology is well established and a growing number of laser beam - object interactions is understood (e.g. by laboratory calibration or controlled experiments), only little is known about the influence of laser beam properties on point clouds in complex environments such as forests. However, the quality of the point cloud is one key factor for successful feature extraction. In this study, we investigate the influence of beam diameter and beam divergence on DBH retrieval using terrestrial laser scanning. Based on Swiss national forest inventory data we simulate TLS measurements in over 500 forest stands using the 3D content creation suite Blender. These simulations provide a rationale for decisions on the choice of a suitable TLS device and survey configurations for forest inventories.

Can terrestrial laser scanning (TLS) provide a new way forward for the study of canopy - ecosystem hydrology interaction?

Mie Andreasen, Thomas Nord-Larsen & Jesper Riis Christiansen

Department of Geoscience and Natural Resource Management, University of Copenhagen, Denmark

Abstract

Plants evaporate rain by two main pathways – transpiration and interception loss. The latter being the limiting factor for the net precipitation entering the soil below the canopy. This net precipitation, termed throughfall, has a profound effect on the ecosystem hydrology of the sub-canopy environment as it constrains soil hydrological dynamics, plant productivity and soil microbial functions. Understanding how different types of plant canopies capture, store, evaporate and transfer water to the soil is therefore important for both ecosystem service and biodiversity studies.

Interception is not entirely dependent on leaf area index indicating that species specific canopy structures, like vertical layering, horizontal density and single tree branch dimensions and orientation, play an important role. Our current conceptual understanding of interception does not include these potentially important plant structures.

We will present the concepts and background for a new research project, INTERCEPTION, where we study the link between canopy structures and interception of rain and soil moisture using point to field-scale measurements. We will use mobile terrestrial laser scanning (mTLS) to derive canopy-structural metrics and relate these to observed hydrological regimes in the canopy and the soil. We will examine how the structural diversity of forests measured by TLS can be used to improve estimation of evapotranspiration, and how it can be scaled in space for integration into hydrological models.

We also hope our input can contribute to a broader discussion of how mapping and modeling of canopy water fluxes in ecosystems using mTLS can be directly applicable for improving studies of ecosystem services and biodiversity.

A new sampling strategy for the temporary part of the Swedish national forest inventory

Anton Grafström[1], Xin Zhao[1,2], Martin Nylander[1], Hans Petersson[1]

[1)]Swedish University of Agricultural Sciences SLU, Department of Forest Resource Management, Skogsmarksgränd, SE-901 83 Umeå, Sweden.

[2)]Presenter

Abstract

We present a new sampling strategy which will be implemented in the forthcoming Swedish NFI for the selection of temporary clusters. The most important difference from the traditional sampling strategies is that auxiliary variables from remote sensing are incorporated into the sampling design. The sample is selected to match population distributions of the auxiliary variables as well as possible. This is achieved by a double sampling approach, where auxiliary variables are extracted for a large initial sample. The second selection is done by the local pivotal method and produces an even thinning of the initial sample. Thus, we make sure that the selected sample becomes much more representative of the population than what is possible by the use of traditional designs. The potential of implementing the new strategy within the Swedish NFI has been evaluated with five auxiliary variables. The increased representativity that we achieve with the new strategy induces up to 95% reduction of the variance of the sample means of remote sensing auxiliary variables compared with traditional designs. For this reason, we conclude that the new strategy has a great potential to achieve large improvements in estimation of many important forest attributes.

Accurate single-tree positions from a harvester: Using a harvester to obtain ground reference data

Marius Hauglin[1], Endre Hofstad Hansen[2], Erik Næsset[1], Jon Glenn Omholt Gjevestad[3] Erik Sørngård[4] and Terje Gobakken[1]

[1)]Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences.

[2)]Norwegian Forestry Extension Insititute.

[3)]Faculty of Science and Technology, Norwegian University of Life Sciences.

[4)]DigPilot, Oslo, Norway.

Abstract

Accurate positioning of single trees registered automatically during harvesting operations opens up new possibilities for reducing the field sampling effort in forest inventories utilising remotely sensed data. We propose to use a harvester to collect single-tree data during regular harvest operations and use these data to substitute or supplement traditional measurements on sample plots. Today's harvesters are capable of recording single-tree information such as species and diameter at breast height, as well as log-quality information registered during the harvest.

In this project a cut-to-length harvester was equipped with an integrated accurate positioning system based on real time kinematic global satellite positioning. At the single-tree level the mean error for the integrated positioning system was below 1 m. The data from the single trees were aggregated to field reference plots, and used as model data in an area-based inventory. In addition to the more traditional plot attributes such as volume, the harvester data also enables modelling of attributes such as saw log recovery.

The sub-meter accuracy obtained with the integrated system and the results from the modelling shows that data acquired with a harvester using such a positioning system may have a great potential as a method for field data acquisition.

Indications of changes in tree stem form, and sampling of trees for robust volume modelling

Juha Heikkinen & Helena M. Henttonen

Natural Resources Institute Finland (Luke), Latokartanonkaari 9, 00790 Helsinki

Abstract

Current Finnish models of tree stem volume are based on measurements from years 1968-72 (Laasasenaho 1982). Since then the typical form of tree stems may well have changed as a result of intensive forest management. National forest inventories (NFI) offer suitable material to analyze this, because the diameter at 6m height (d_6) has been measured in addition to the breast height diameter ($d_{1.3}$) and the height (h) of sample trees. We compared NFI results based on two-predictor models, using $d_{1.3}$ and h, to those based on three-predictor models, also using d_6. For the sample trees of NFI11 (years 2009 – 2013), stem volume estimates based on two-predictor models are higher in average than those based on three-predictors models. Some kind of change is indicated by the fact that the estimates based on the two model families are clearly more similar in NFI6 (1970-1976) sample tree data. A regional trend was also observed: The differences in NFI11 were rather small in the north and increased towards south and west.

A direct analysis of the changes in d_6 in relation to the other tree dimensions, will also be presented.

The indicated changes have motivated an intensive measurement campaign with the aim of updating the volume and stem form models. During two field seasons in 2017 and 2018, approximately 4,800 trees from 570 NFI sample plots will be measured both with terrestrial laser scanning and traditional field assessments of $d_{1.3}$ and h. We shall describe how the sample plots were chosen in order to ensure that the whole variety of Finnish forests is well represented. Anticipated robustness properties of two-predictor models are analyzed on the basis of data from earlier NFIs.

Reference

Laasasenaho, J. (1982). Taper curve and volume functions for pine, spruce and birch. *Communicationes Instituti Forestalis Fenniae* **108**: 1-74.

First results from tree measurements using mobile laser scanning systems in Sweden

Holmgren, J., Willen, E., Tulldahl, M.

The Swedish University of Agricultural Sciences

Abstract

An experimental mobile laser scanning system has been developed and validated for the measurement of trees. The sensor's position is difficult to estimate in a forest environment because of poor signals from global navigation satellite systems underneath dense tree canopies. Therefore, initial estimates of the sensor trajectory were estimated in two different ways: (1) using a high precision inertial navigation system (INS) and (2) using a stereo-camera combined with a low cost and low precision INS. The initial estimates of the sensor trajectory were then corrected using dynamic calibration, tailored for forest environments, using high density 3D laser measurements from surrounding trees and the ground. The laser data were collected using a Velodyne VLP-16 scanner emitting ca 300 000 pulses per second. Tree positions and stem diameters were derived from the laser data. The estimates were validated on large plots with 20 m radius with known tree positions, measurements from static ground-based laser scanning, and manually measured stem diameters. Automatic tree stem position and diameters were also derived with data from the commercial system ZEB1 and validated using data from the same field plots. The first results are promising from both the experimental (also with low cost components) and commercial systems. The results indicate that mobile laser scanning systems have the potential to be efficient and robust tools for forest inventory.

3D measurement of tree health with multispectral terrestrial laser scanning

Samuli Junttila[a,b], Mikko Vastaranta[a,b], Riikka Linnakoski[a], Junko Sugano[c], Harri Kaartinen[b,d], Antero Kukko[b,d], Markus Holopainen[a,b], Hannu Hyyppä[b,e], and Juha Hyyppä[b,d]

[a)]Department of Forest Sciences, University of Helsinki, 00014 Helsinki, Finland.

[b)]Centre of Excellence in Laser Scanning Research, Finnish Geospatial Research Institute FGI, 02431 Masala, Finland.

[c)]Department of Biology, University of Turku, 20014 Turku, Finland.

[d)]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute FGI, 02431 Masala, Finland.

[e)]Department of Built Environment, Aalto University, P.O.Box 15800, 00076 Aalto, Finland.

Keywords: *Forest health, terrestrial laser scanning, LiDAR, multispectral laser scanning, leaf water content, monitoring.*

Abstract

Tree health evaluations have traditionally been based on subjective visual assessments that are prone to error and bias; thus, an objective method for measuring tree health is needed. Equivalent water thickness (EWT), a measure of leaf water content, is an important early indicator of tree stress caused by a variety of factors including pest insects, pathogens and drought. Early detection of pest insects and pathogens is vital in reducing the damages and costs of decreased tree growth and tree mortality. Recent investigations have explored the use of backscatter intensity information from terrestrial laser scanners (TLSs) to obtain EWT, but few studies have investigated the use of multiple wavelengths.

Here we tested the feasibility of three-wavelength terrestrial laser scanning in detecting leaf water content from Norway spruce seedlings (n = 78). To simulate a drought event, the seedlings were subjected to number of different treatments, which all included different level of watering during 8 weeks. During this period, sub-samples of seedlings were randomly selected from each treatment for laser scanning and destructive measurements of EWT at 10 time intervals. The relationship between the measured EWT from the needle samples and laser intensity features, using 690 nm, 905 nm and 1550 nm wavelengths, were determined. The results showed a relationship of R^2 = 0.88 (RMSE = 0.0037 g/cm^2) between the measured EWT and the ratio of mean backscattered laser intensity from 905 nm and 1550 nm wavelengths. The investigated method could potentially provide a tool for automated tree health classifications in the future.

Experience acquired through a decade of terrestrial laser scanning measurements

Ville, Kankare[1)3)]; Markus, Holopainen[1)3)]; Mikko, Vastaranta[1)3)]; Ninni, Saarinen[1)3)], Xinlian, Liang[2)3)]; Xiaowei, Yu[2)3)]; Harri, Kaartinen[2)3)]; Antero, Kukko[2)3)]; Juha, Hyyppä[2)3)]

[1)]Department of Forest Sciences, Faculty of Agriculture and Forestry, University of Helsinki, Latokartanonkaari 7, 00014, Helsinki, Finland, first.last@helsinki.fi

[2)]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute (FGI), National Land Survey of Finland, Geodeetinrinne 2, 02430, Masala, Finland, first.last@nls.fi

[3)]Centre of Excellence in Laser Scanning Research, Finnish Geospatial Research Institute (FGI), 02431, Masala, Finland

Abstract

Point clouds from terrestrial laser scanning (TLS) have now been collected, processed, and evaluated as a tool for forest inventory in research campaigns for over a decade. TLS data have shown to offer opportunities for small scale and high detail 3D mapping of e.g. individual trees within a sample plot or attributes of a single tree. TLS data have already been used to measure e.g. tree location, diameter-at-breast-height and height but it also creates added value through additional tree attributes (e.g. stem curve and external quality) that are costly to measure with traditional means. In addition, TLS offers new possibilities in single-tree level modelling and model development (e.g. volume and biomass components). But the main challenge for operational TLS data is to obtain comprehensive point cloud (i.e. point cloud without shadow gaps) from which e.g. all trees within a specific area could be mapped. This can be achieved by adding more scanning locations within the area but the optimal scenario for cost and value of the data should be found. The other challenge is tree species recognition, which has been left for smaller attention although it is critical factor in operational forestry. The aim of this overview is to communicate our experiences with TLS data acquisition, processing, and results achieved in our studies: what we have learned from the past ten-year period and what we think are the main obstacles to be solved for TLS to be a practical tool for operational forestry.

Measuring stem diameters with close-range photogrammetry

Susann Klatt[1], Johannes Breidenbach[2], Rasmus Astrup[2] and Marlies Pötschke[3]

[1)]Thünen Institute of Forest Ecosystems

[2)]Norwegian Institute of Bioeconomy Research

[3)]Technical University Dresden

Keywords: *Close-range photogrammetry, Criterion, automation*

Abstract

Information and measurement technologies are developing fast, which will influence monitoring concepts in forest inventory. New advanced methods are tested for measurement of tree growth, stand parameters and forest resources. Plot-level measurements include diameters at different heights as they describe stem taper and allometry and are therefore essential input to estimate tree volume and biomass.

A widely known and often tested monitoring technique to measure tree and stand parameters is Terrestrial Laser Scanning (TLS). In contrast, this study focusses on Close-Range Photogrammetry (CRP) approaches as an easy and cheap alternative. The measurements were done for 50 trees in south eastern Norway with: (1) images taken with two reflex cameras mounted on a stereo rig (RCS), (2) images taken all around trees with a single reflex camera handheld (SRCH) and (3) a Criterion dendrometer (CRD) and calliper as reference.

Main processing steps for CRP were automated using Python in Agisoft. Diameters were measured in the generated 3D dense point clouds using open source software and compared with results from the other devices. With RCS method images from 27 out of 50 trees could be matched and scaled using the known camera distance with satisfying result. Whereas with SRCH images from 43 out of 50 trees could be matched but only 22 could be scaled with the help of an uncoded marker (chessboard) until now. Despite the relatively high failure rate, the CRP data is promising, as the level of detail in resulting point clouds is similar to data generated by TLS. New samples are already planned in Germany with improved methods for better automation of the most processing steps.

Using statistical reconstruction methods for studying optimal sample designs in forest inventories

Mikko Kuronen[1], Henrike Häbel[2], Helena Henttonen[1], Pavel Grabarnik[3] and Mari Myllymäki[1]

[1)]Natural Resources Institute Finland (Luke)

[2)]Chalmers University of Technology and University of Gothenburg

[3)]Institute of Physico-Chemical and Biological Problems in Soil Science, Pushchino, Russia

We suggest statistical reconstruction methods to extend tree patterns of relatively small plots to larger areas, e.g. stands. The reconstruction takes into account relative positions of trees as well as their sizes and qualitative marks, e.g. tree species. It is based on a new family of summary functions which allow to describe structural properties of spatial patterns of forest stands in more detail than conventional summaries used for this purpose. We reconstruct patterns for different types of forests over the area of Finland. Finally, we use the generated patterns for a study of optimal plot design.

International benchmarking of terrestrial laser scanning for forest inventories

Xinlian, Liang[1,2] Juha, Hyyppä[1,2], Harri, Kaartinen[1]

[1)]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute (FGI), National Land Survey of Finland, Geodeetinrinne 2, 02430, Masala, Finland, first.last@nls.fi

[2)]Centre of Excellence in Laser Scanning Research, Academy of Finland, Helsinki, Finland

Abstract

Terrestrial laser scanning (TLS) is an automated and effective technique for acquiring detailed tree attributes in forest plots, leading to more sustainable development in silviculture and savings for forest owners and industry. During the last two decades, tremendous efforts was put into research to develop methods for tree attributes estimation from TLS data. Impressive results reported in recent years. And it is anticipated to be used in national forest inventories (NFIs). However, there is still a lack of proper understanding the performance of TLS, especially in forests with varying structure and in development stages. It is still an open question whether TLS plot inventories support operational work or even make major field measurements.

To understand the current status of TLS in plot inventories, an international benchmark study was launched in 2014 by EuroSDR and coordinated by FGI. With standardized data and evaluation method the extraction of the DTM, tree positions, and stem curve were evaluated. National mapping agencies, companies and research organizations around the world were invited to join the project. The methods in the benchmarking showed a high level of automation and provide results at reasonable accuracies. The results indicate how measurement setup, reconstruction method, and the forest conditions impact the tree attribute estimation.

Observing changes in stem form of individual trees by means of TLS-time series

Luoma, V.[1], Vastaranta, M.[1], Saarinen, N.[1], Kankare, V.[1], Kaartinen, H.[2], Holopainen, M.[1], Hyyppä, J.[2]

[1] Department of Forest Sciences, University of Helsinki

[2] Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute (FGI)

Abstract

Terrestrial laser scanning (TLS) is a technique that enables characterization of an individual tree in very detailed manner and at the same time it can be used for collecting information on the growth environment of the tree. Although TLS has been used in forest research already more than 10-years, the possibilities of the technique for forest monitoring have not been investigated thoroughly. For forest monitoring, repeated TLS measurements would allow us to create detailed 3D time series from sample plots and measure changes in various tree characteristics.

The aim of this study is to monitor growth of the single trees in varying forest conditions in southern Finland using TLS time series and automatic stem diameter measurement algorithm. Especially we concentrate on investigating changes in stem form. With sample plots including variation in tree species, age and size, it is also possible to investigate the processes affecting to the growth and changes in the stem form.

As a result, the study aims to provide improved knowledge on applicability of TLS in detecting the tree growth from TLS time series. We also expect to find out which tree and stand structural factors, along with environmental variables extracted from TLS-data, could be used as indicators for explaining variation in tree growth. These results are required as a base for further studies related to tree growth modelling with TLS as well as for how to use TLS in collecting information from permanent sample plots in forest inventories.

Prediction of forest attributes using 3D data from aerial images and field data from the national forest inventory

Mats Nilsson, Kenneth Nyström, André Wästlund, Peder Axensten, Mikael Egberth, Jonas Jonzén and Håkan Olsson

Department of Forest Resource Management, Swedish University of Agricultural Sciences, Umeå, Sweden.

Abstract

In Sweden, a high resolution (12.5 m grid cell size) raster database with predictions forest attributes such as stem volume and tree height has been created for almost all forest land by combining airborne laser scanning (ALS) data and field data from the Swedish National Forest Inventory (NFI). The ALS data used was collected by the Swedish National Land Survey (NLS), primarily with the purpose to create a new national digital elevation model (DEM). The predicted forest attributes maps are available free of charge at the Forest Agency's homepage (http://www.skogsstyrelsen.se/skogligagrunddata).

In 2016, the NLS started to deliver 3D point clouds derived from aerial photographs, as a part of their operational aerial image production. The point clouds used origins from images photographed between 2014 and 2016 and have a point density of 4 points/m^2 in southern Sweden and the coastal areas in northern Sweden. The point density in the remaining parts of northern Sweden is 1 point/m^2.

Using these new point clouds from aerial photogrammetry, regression models were used to relate the selected forest variables, or transformations of the variables, to metrics derived from the 3D data. Preliminary results show stand level RMSEs for stem volume, basal area, mean tree height, and mean stem diameter of approximately 22%, 20%, 9%, and 15 %, respectively.

Although the RMSEs are slightly higher than the ones obtained for the ALS predictions in the national raster database, a new national dataset with up-to-date predictions from photogrammetric point clouds will useful for forest management planning.

Automatic determination of tree position and stem diameter using a mobile terrestrial laser scanner

Ivar Oveland[1], Marius Hauglin[2], Terje Gobakken[2], Erik Næsset[2] and Ivar Maalen-Johansen[1]

[1)]Faculty of Science and Technology, Norwegian University of Life Sciences.

[2)]Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences.

Abstract

The recent development of terrestrial laser scanning (TLS) systems in terms of capacity and weight have made these systems possible tools for tree recordings on field plots. A typical approach is to use multiple TLS scans which are merged into a single point cloud before extraction of information such as single tree positions and diameter at breast height (DBH). This procedure requires a good position and orientation accuracy for each scan location. In the current project we take a different approach and propose a method that can operate under a relatively coarse positioning and orientation solution, using a mobile device based on a Velodyne VLP16 laser scanner. In this approach the laser measurements are divided into limited time intervals determined by the laser scan rotation. Tree positions and DBH are then automatically extracted from each individual laser scan rotation. The estimated tree positions and DBH are subsequently processed and merged to give a representation of the trees on a field plot.

In a test with a small reference data set from a single field plot consisting of 18 trees, it was found that 14 trees were automatically identified by this method. The estimated DBH had a mean differences of 0.9 cm and a root mean squared error of 1.5 cm. The proposed method enables fast and efficient data acquisition and a 250 m2 field plot was measured within 30 sec.

Preliminary results of the Finnish TLS data: from point cloud to QSM and beyond

Pitkänen TP, Kangas A.

Natural resources Institute Finland

Abstract

Since last year, Luke has been collecting data using Leica ScanStation P40 terrestrial laser scanner (TLS). Scanning has been targeted on circular field plots where trees have been detected up to a maximum distance of 9 m. At each plot there have been made several scans, which have further been merged into a single combined point cloud and analyzed using quantitative structure modelling (QSM) approach developed by Raumonen and Kaasalainen. These results have been then compared with field-measured variables such as DBH and tree height, aiming at to estimate the accuracy of TLS-derived data and find best practices for both fieldwork as well as data analysis.

So far, results are mainly promising: QSM method is able to detect majority of the field-detected trees, follow their structure correctly, and provide reasonable estimates of tree diameters at variable heights. However, both QSM-derived DBH and tree height are normally lower compared to the field-measured values. Difference in DBH derives mainly from a different base height which is likely to be affected by both ground vegetation as well as rapid diameter variation at the stump level. In terms of tree height, upper parts of the stem are easily masked by lower branches and simultaneously affected by wind in the combined point cloud, thus hindering the correct evaluation of the QSM cylinders. Depending on the focused application and its expected outcomes, these characteristics may be more or less significant for the results. As one of Luke's aims is to collect data for improved taper curve estimation, however, gaining as correct diameter values as possible regarding to the whole stem is essential.

After the initial TLS tests in summer 2016, several strategies have been developed which have a potential to improve the gained results. First, field data collection has been made more flexible in terms of the scanning locations, aiming at to produce good quality data without excessive fieldwork at any given plot. Second, local circle fitting procedures based on data from separate scans instead of the combined point cloud are tested along the QSM-indicated stem structure. Third, detection and adjustment of the base

height is improved by reflective bands (duct tape) which are stuck at a defined height level and can be detected by TLS intensity values. And fourth, point cloud remaining above the detected QSM top cylinder is analyzed to gain a better estimate of the actual tree height. Preliminary results of these approaches and their applicability for improved detection of tree diameters / heights are presented.

Evaluation of standing timber using stem curve and branch structure data derived from terrestrial laser scanning point clouds

Jiri Pyörälä[1,2,3,*], Mikko Vastaranta[1,2], Ninni Saarinen[1,2], Ville Kankare[1,2], Xinlian Liang[2,3], Juha Rikala[1], Markus Holopainen[1,2], Marketta Sipi[1], Juha Hyyppä[2,3]

[1)]Department of Forest Sciences, University of Helsinki, Helsinki, FI-00014, Finland

[2)]Centre of Excellence in Laser Scanning Research, Finnish Geospatial Research Institute, Masala, FI-02431, Finland

[3)]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute, Masala, FI-02431, Finland

*Corresponding author e-mail: jiri.pyorala@helsinki.fi

Abstract

Individual logs are evaluated and sorted at sawmills using optical and X-ray scanning devices. However, optimal utilization of forest resources would require means to evaluate the standing timber prior to harvesting. This could be aided by means of terrestrial laser scanning (TLS) that enables acquisition of detailed 3D point cloud data of forest environment, including data on stem and branch properties of individual trees. The aim of this study was to compare TLS point clouds to X-ray scanning images in deriving wood quality indicators, i.e., log-specific bottom conicality, tapering, top diameter, maximum knot size and knot volume, that are used at sawmills to sort logs. TLS multi-scan point clouds of 52 standing Scots pine (*Pinus sylvestris* L.) trees were collected on a 2.2 ha forest stand in southern Finland. The trees were felled and scanned with X-ray at a sawmill. An automated, quantitative assessment method was used to extract stem curves as well as branch diameters and angles from the TLS point clouds. Based on the extracted features, the trees will be bucked into logs and the aforementioned wood quality indicators calculated for each log and compared to corresponding measurements from X-ray scanning images. We expect to gain new information on feasibility of TLS point clouds to collect information on wood quality of individual trees. The potential of the approach to contribute to optimal forest resource utilization will be discussed.

TreeQSM – A tree architecture reconstruction method from TLS data

Pasi Raumonen, Markku Åkerblom, Mikko Kaasalainen

Tampere University of Technology, Laboratory of Mathematics, pasi.raumonen@tut.fi

Abstract

We present our TreeQSM method for automatic reconstruction of accurate quantitative structure models (QSM) of trees from terrestrial laser scanner (TLS) data. A QSM is a hierarchical collection of simple building blocks, usually circular cylinders, that model local topological, geometric and volumetric details of a tree. As a whole the collection of building blocks forms an accurate 3D model of the tree's woody architecture. From a QSM we can extract many useful features commonly used in forest inventory such as diameters, taper and volume of stem and stem quality measures such as number, diameters and angles of branches originating from the stem. We can also estimate total number, volume and length of branches and other overall tree dimensions and distributions such as volume as a function of diameter or branching order. We also demonstrate how QSM derived features allow highly accurate and automatic classification of tree species in Finnish forests. TreeQSM method assumes the input point cloud contains only one tree, but we also demonstrate possibilities for automatic tree extraction from TLS point clouds. TreeQSM-method has been implemented with MATLAB and will be freely available for researchers.

Developing species-specific taper curve models with terrestrial laser scanning data

Saarinen, Ninni[a,c], Liang, Xinlian [b,c], Kankare, Ville [a,c], Vastaranta, Mikko [a,c], Pyörälä, Jiri [a,c], Holopainen, Markus [a,c], Hyyppä, Juha [b,c]

[a)]Department of Forest Sciences, University of Helsinki, 00014 Helsinki, Finland

[b)]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute FGI, 02431 Masala, Finland

[c)]Centre of Excellence in Laser Scanning Research, Finnish Geospatial Research Institute FGI, 02431 Masala, Finland

Keywords: *LiDAR, forest mensuration, taper curve modelling, forest inventory*

Abstract

Traditionally, development of taper curve models and stem volume equations require destructive sampling. Therefore, developing and updating existing models is expensive and time consuming. In Finland, it has been observed that the existing stem volume equations, based on taper curve models, are biased in some regions and there is a need for efficient data collection method for updating these models. Terrestrial laser scanning (TLS) has been studied actively in recent years and it has proven to provide individual tree attributes accurately. Therefore, TLS data can be presented as a feasible means of characterizing stem form in a detailed manner. The aim of this study is to increase understanding of the suitability of TLS data in developing species-specific taper curve models. The data include 24 sample plots from which multiple scans from each plot were acquired in the summer of 2014. The scans from each sample plot were georeferenced as one TLS point cloud for each plot. Diameters along a stem were measured from these point clouds resulting with taper curves from 2736 spruce, pine, and birch trees. Information on tree species, diameter-at-breast height, height, and site type was collected at the same time as TLS data. Regression analysis is used for deriving coefficients for species-specific taper curve models based on TLS measurements. Stem volume estimates obtained from the developed taper curve models are compared to existing models as well as destructive measurements.

Improving Multi-Source National Forest Inventory by 3D aerial imaging

Tuominen, S., Pitkänen, T.' Balázs, A. and Kangas, A.
Natural Resources Institute Finland

Abstract

Optical 2D remote sensing materials such as aerial photographs and satellite imagery have been used in forest inventory for a long time. In recent years, airborne laser scanning (ALS) has been adopted for the estimation of forest attributes at stand and sub-stand level. ALS data are particularly well suited to the estimation of forest attributes related to the physical dimensions of trees due to its 3D information. Similarly to ALS, it is possible to derive a 3D forest canopy model based on aerial imagery only using digital stereo-photogrammetry. In this study we tested the combination of photogrammetric 3D data that was derived from archived aerial images originally acquired for orthomosaic production in combination with satellite and aerial imagery in the estimation of forest inventory variables. The estimates were compared to estimates based on traditional 2D satellite and aerial imagery as well as the combination of ALS and aerial imagery. Both 2D materials were very close to each other in accuracy, as well as both the 3D materials. On the other hand, the difference between the 2D and 3D materials was very clear. 3D material produces a map where the hotspots of volume, for instance, are much clearer than with 2D material. The spatial correlation in the map produced with 2D material shows a lower short-range correlation, but the levels of correlation approach the same level after 200 meters. The difference may be of importance, for instance, when analysing the efficiency of different sampling designs and when calculating the cutting possibilities.

New opportunities for high-resolution wall-to-wall forest cover and tree type mapping

Lars T. Waser[1], Christian Ginzler[1], Nataliia Rehush[2]

[1)]Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Department of Landuse Dynamics, Zuercherstr. 111, 8903 Birmensdorf, Switzerland; waser@wsl.ch

[2)]Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Department of Forest Resources and Management

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Abstract

Wall-to-wall forest attribute maps are a fundamental input for the changing requirements of regional and national forest inventories (NFIs). In this research, we present the great potential of repeated and routinely acquired aerial imagery within two novel approaches for generating repeatable and objective countrywide forest cover and tree type maps.

Digital aerial images, have lately been incorporated into operational NFIs and the required estimates obtained from remote sensing-based maps can now be expressed in forms similar to sample-based estimates. However, there are currently no operational attempts to produce wall-to-wall forest attribute maps in the framework of a National Forest Inventory (NFI).

The forest cover map is based on DSMs from image-based point clouds of airborne digital sensor (ADS80) data and DTMs from LiDAR surveys. It fully takes into account the four key criteria of minimum tree height, crown coverage, width, and land use – the requirements of the Swiss NFI forest definition. Validation with terrestrial and stereo-interpreted NFI plots revealed 97% agreement overall. Our mapping approach is superior to existing products due to its national coverage (41,200 km^2), high level of detail, regular updating, and implementation of the land use criteria.

The tree type map is based on ensemble modelling (RF, SVM, k-NN and logistic regression) using the same ADS80 imagery and was applied for 220 subsets covering entire Switzerland. It incorporates original image bands, remote sensing indices and 3D point data as predictor variables. 10-fold-cross-validation revealed high overall model accuracies (98.1-

99.3%). Validation using independent NFI plot data revealed lower accuracies of around 5-8%.

For both approaches, validation was refined and incorporates different NFI height levels and productions regions. The produced wall-to-wall data sets will be of emerging practical relevance in the framework of NFIs.