Cost-Efficient Semi-Automatic Forest Inventory Integrating Large Scale Remote Sensing Technologies with Goal-Oriented Manual Quality Assurance Processes

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Introduction

Up to date forest inventory data is an important foundation for forest management. The data should be available for large areas and at high quality to allow for sustainable decision-making, precise value determination and reporting. But the costs for the data acquisition become more and more important. So the objective of this paper is to find cost-efficient ways to acquire forest inventory data at higher quality but at lower costs.

We present a flexible new approach to semi-automatic forest inventory on a stand-wise level. Based on remotely sensed data, automatic and manual processes are combined leading to a practically relevant new methodology. The applicability of these new methods has already been proven on large scale test areas (approximately 800 km²) within the context of the "Virtual Forest“™ (Rossmann et al. 2007)(Rossmann et al. 2008), a research project of the German federal state of North Rhine Westphalia supported by the European Union (EU).

In the following, the basics of automatic data processing, object oriented modeling of forest inventory data as well as quality assurance processes will be outlined and the results will be compared against the background of real world applications.

Approach

Traditional, completely manual acquisition processes in stand inventory can provide high quality data when carried out by well trained experts. But especially in today’s economical situation quality often suffers from cost and time pressure.

For large scale applications automatic data acquisition can offer a cost-efficient alternative. In the field of forest inventory such processes are then usually based on remotely sensed data. A significant deficiency of an automatic derivation of inventory data can be a rather unspecified quality status of the data and the lack of detailed information concerning stand attributes which cannot be derived from remote sensing data.

In our approach, automatic and manual processes are combined to benefit from each other. Automatic processes for object and information extraction were developed that are based on remotely sensed data and use multi sensor fusion techniques. The algorithms are designed in such a way that their data sources can flexibly be chosen by availability and cost-efficiency. The counterpart of these automatic processes are semi-automatic manual processes that were defined and implemented to assure the quality and to allow for data refinement of the automatically extracted data.

Basic means

All the aforementioned algorithms and processes were implemented into a standard-compliant 4D-GIS (Figure 1) that is based on the simulation system VEROSIM®, originally developed at the MMI together with industrial partners as a robot simulation and Virtual Reality system.

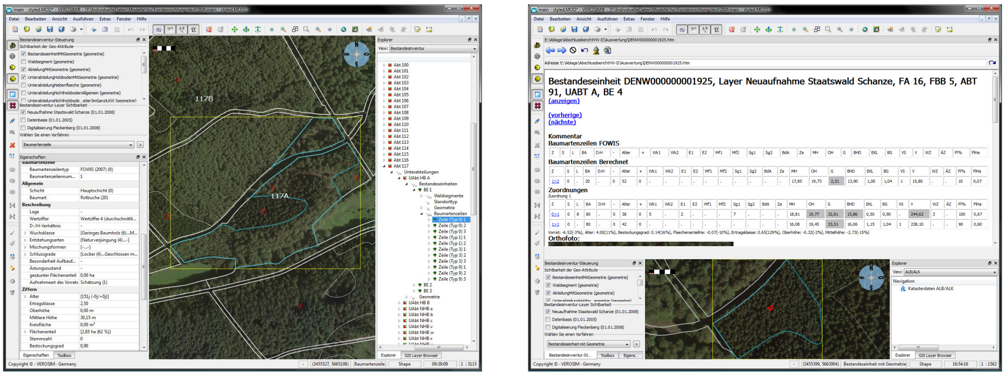

Figure 1. User interface of the 4D-GIS (left) and comparative table (right)

The developed system is considered a 4D-GIS, as the fourth dimension, the time, is an inherent parameter for all data storage operations and calculations: It is thus capable of supporting a (simulated) "look into the future" as well as a "look into the past" based on historic data. To easy the operation, it offers standard-compliant interfaces. It supports various vector and raster data sources such as Shape-Files and databases, WFS, WMS, WCS, CSW, SQL as well as image and raster data formats. Also, it is OGC-conformant with respect to its geometry representation, geometry operations and query infrastructure. Due to the flexibility of the underlying simulation system the 4D-GIS scales well from ruggedized portables to computer clusters and thus the same software can be used as a portable forest information system as well as a comprehensive forest inventory data calculation cluster running on multiple PCs in parallel.

Another important aspect of the system is its object-oriented data model (not only) for the inventory data. Forest units are represented by objects and the administrative hierarchy is modeled by relations between these objects. This enables an intuitive processing of the inventory data. As objects like stand units carry their geometrical description as well as the various forestry relevant attributes, data consistency is ensured on all levels of abstraction.

Remotely sensed data

The remotely sensed data used by the different algorithms was acquired for the two test areas with a total size of approx. 800km² by airplane and satellite. The aerial surveys delivered LIDAR data from a Riegl LMS-Q560 (Riegl 2009) scanner with 4-6 points per m² at full-waveform on a 40cm raster. The LIDAR products used were a Differential Model (DM) (also known as normalized Digital Surface Model (nDSM) or Canopy Height Model (CHM)), a Filled Digital Terrain Model (FDTM) and a Digital Surface Model (DSM).

The aerial photo data was acquired by a DLR HRSC-AX150 (Scholten et al. 1999) on a 20cm and by a Microsoft UltracamX on a 10cm raster. It covers red, green and blue (RGB) as well as near infrared (CIR) channels and was ortho-rectified using the DSM. The SPOT satellite system provided middle infrared images on a 10m raster.

Automatic processes

Tree species classification is a prerequisite to automated forest inventory. An algorithm for tree species map generation was developed (Rossmann et al. 2009) that bases upon a decision tree approach. The classification is object-based using tree candidates derived from the DM. It uses the spectral information from the aerial surveys and from the SPOT satellite to gradually distinguish between the four most common tree types in the test area (spruce, beech, douglas fir, larch). Figure 2 (left) shows a result of the tree species classification as an overlay on top of the RGB. As a byproduct of the classification, reliability maps are automatically generated. These reliability images give a hint on areas where the result needs to be confirmed by an expert.

Stand segmentation builds forest segments of similar stock of trees. We implemented a region merging approach (Rossmann et al. 2009) based on the standard deviation of wavelet coefficients of RGB, CIR and DM to automatically generate such segments. To enhance the results, a simplified version of the tree species map (with classes 'no forest', 'deciduous' and 'coniferous') serves as an additional input. As the algorithm works on raster data, the resulting segments are transformed into vector shapes, smoothed and snapped to the borders of the segmented reference geometry. Figure 2 (right) shows an example result of the stand segmentation before the smoothing step.

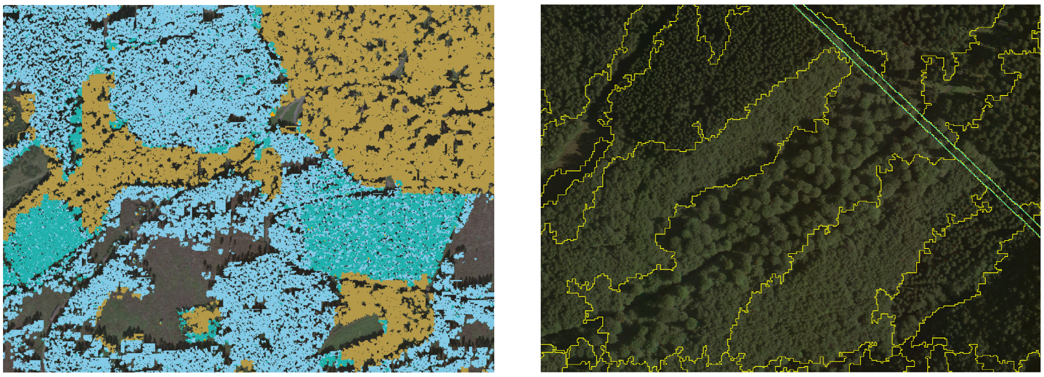

Figure 2. Results of the tree species classification (left) and stand segmentation (right)

A **stand attributes evaluator** calculates various key attributes of the stand area (Kramer 1995). The tree species map is used to determine the different tree species and their percentages in a stand unit. The DM is the basis for the calculation of dominant height and stock density (the latter based upon the covered area). The yield class can be derived from intersection with maps for water balance levels existing for the test areas (Asche 2006). Other attributes like age, mean height, diameter at breast height (DBH), the number of trees and stock of wood can then be derived using statistical tables.

As the results from the segmentation process are generated on a sub-stand level to capture all relevant features of the forest, a **generalization process** is used to automatically merge similar neighboring segments into bigger units. The similarity measure is defined on stand attributes (percentage, dominant height, age …) calculated for the segments using the stand attributes evaluator (see above).

Besides stand attributes, also **attributes describing the site** can be calculated. The process uses the FDTM to determine height, slope and exposition of the site and derives trophic level and water balance using existing maps (Asche 2006).

Manual processes

Well-defined processes for in-office and on-site manual data acquisition, quality assurance and data refinement provide means for specialists to combine their expertise with automatic heuristics. Thus not only recurring standard tasks are left to the automatism but the professional user will automatically be informed and supported by the system to solve just some few remaining difficult stand situations.

Concerning stand attributes, the manual processes are based on the comparison of calculated with old inventory data. In North-Rhine-Westphalia such data is available for all state-owned and partly privately owned forests. The system automatically informs and supports the user in solving remaining difficult stand situations and gives hints on deviations of old and calculated values.

For this task tools were developed such as the comparative table generator and the comparative dialog and embedded into the 4D-GIS. The comparative table is an analysis table automatically generated to compare huge numbers of stands. If the relative deviation of two values is low (0-10%) a field is marked green, if medium (10-20%) yellow and if high (above 20%) red. The table can be used for large scale comparison to insure overall quality ("everything is marked green") and to detect problematic stand situations ("here's something marked red"). It contains an overview table of all treated stand units were attributes such as percentage, dominant height, stock density, yield class, age and stock of wood are compared. For each stand unit there is an additional page (Figure 1 right) with a detailed tree-species-wise comparison of its attributes. Images of the stand borders with the RGB, DM and tree species map are added to give an overview of the stand situation from remote sensing data. The table can be used directly inside the 4D-GIS with an interactive link-based connection from entries in the table to objects in the system. But, as it's HTML-based, it can also be viewed on an arbitrary web browser to even evaluate the results without the 4D-GIS.

The comparative dialog is an even more interactive tool. It is used to actively merge the two data sets thus updating the calculated inventory data on the one hand and adding detailed stand descriptions from manual surveys to the calculated data on the other hand. For this it compares the tree-species-wise attributes of a single stand unit "in real-time". It features several treatments for the data. For example, if a tree species is only listed in one set of attributes (i.e. calculated or old data) it can be assigned to the merged data set, to the rejected data set or it can be merged with another tree species. The latter can be used to automatically correct errors in the tree species map. Old inventory data from manual surveys often contains detailed descriptions of stand situations that cannot (yet) be derived from remote sensing data. These details can automatically be added from the old inventory data to the appropriate calculated data thus refining the calculated data.

Results

As mentioned earlier, the described methods have been tested for the test areas of the "Virtual Forest"™ project. Comparison with manual acquired forest inventory data on an investigated sub area showed only a very small difference in the key attribute "stock of wood". Taking a look at a typical test scenario, the manual survey showed 12,378.53 and our calculation 12,733.01 solid cubic meters – a difference of only 354.48 solid cubic meters (i.e. 2.8%). Further research on the cause of local deviations revealed errors on both sides. The algorithms still need adaptation to extreme stand situations (e.g. extreme slopes). But also the manual survey showed problems, for example in stands with complex borders were whole tree groups were mistakenly assigned to neighboring stand units.

Conclusions

Based on the combination of automatic and manual processes, our newly developed methods allow for large scale forest inventory at higher quality but at lower costs. The cost-efficiency is due to the large scale computation of inventory data, the flexible choice of data sources and the fact that work can be prepared in-office. The higher quality is achieved by on-site focus on data refinement and quality checks.

Future Work

The automatic algorithms will be further optimized based on calibration using ground-truth data and on feedback from manual interaction as well as from production processes. In addition to this, we plan to add more tree species to the tree species classification algorithm using new test sites and multispectral data sources.

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