FOREST INVENTORY AND BIOMASS ASSESSMENT BY THE USE OF AIRBORNE LASER SCANNING METHOD (EXAMPLE FROM SIBERIA)

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ABSTRACT:

The use of aerial laser scanning method provides a number of principally new possibilities on remote sensing of forest vegetation and specifically of a disturbed forest ecosystems (after wild fires, logging operations, insect outbreaks etc.) which area increases year by year in Siberia. The high efficiency of laser sensing survey (up to 50-70 thousand original measurements per second) combining with the spatial resolution and accuracy of a few centimeters allow making the effective algorithms of morphology analyses, ensuring automatic extraction of many important information characteristics of a disturbed forest ecosystems. The analysis of stand structure integrated with GPS data, digital aerial video- and highly accurate (10-15 cm of actual linear resolution) photographic images makes it possible to highly reliable interpretation of different types and layers of forest vegetation separating it by a tree species, density, degree of disturbance and other parameters. The consequent processing of laser profiling data and digital aerial photographs using original ALTEXIS software, integral calculations, the Fourier and mean free path analysis makes possible to get such important and precise information on vegetation as forest structure, tree species composition and timber stock at a direct way or by mediate - on correlation with morphometric parameters. The regression method with the use of allometric functions provides accurate and effective assessment of stand biomass when processing a laser profiling data. The methodology aspects of airborne laser scanning method use for an aerial survey and biomass assessment at disturbed forests of Siberia are considered in the paper. The description of the morphology algorithms is shown. The results of practical application of airborne laser scanning by Optech Inc. ALTM-2050 machine for forest biomass evaluation in Central Siberia are discussed.

INTRODUCTION

Laser terrain mapping and survey is important constituent part of the newest methods and technologies of geoinformatics and digital photogrammetry and is widely adopted at solving many tasks of ecological monitoring and forest mapping and inventory. Laser forest terrain mapping and survey can be done independently and in complex with space and aerial digital video- and photography combined with ground sampling as well.

In North America laser mapping methods using satellite and aircraft platforms was developed and widely practiced at geodesy, cartography and forest inventory and survey (Aldred et al., 1985; Krabill et al., 1987; Chappelle et al., 1989; Kalshoven et al., 1990; Ritchie et al., 1993; Blair et al., 1996; Lefsky et al., 2001; Ackermann, 1999; Means et al., 1999, 2000, 2001; Dubayah et al., 2000; Magnussen et al., 2000; Montes et al., 2000; Sun et al., 2000; Wulder et al., 2000; Andersen et al., 2001; Kraus et al., 2001; Ziegler et al., 2001; McCombs et al., 2003; Todd et al., 2003).

In Russia (at that time Soviet Union) laser methods, directed toward forest resources' survey had been developed before onboard aircraft and satellite lasers appear. There are mainly investigations which had been done at Leningrad Forestry Research Institute (LenNIILH) by V.I. Solodukhin with coauthors, who demonstrated high efficiency of forest laser profiling combined with traditional analog aerial photography for timber cruising purpose (Solodukhin et al., 1977, 1985; Stolyarov et al., 1987).

During last years with appearance and availability at civil branches of economy of satellite positioning and navigation systems (US GPS and Russian GLONASS), satellite and aerial laser scanning and digital video- and photography, new possibilities appears for remote sensing of terrestrial ecosystems and forest cover with highly accurate measuring relief and heights of ground objects at about ±10-15 cm and positioning of their space coordinates at about ±15-20 cm and higher accuracy (Hyyppä et al., 1999; Danilin et al., 2000, 2001; Medvedev, 2004; Danilin, 2003; Holmgren et al., 2003; Popescu et al., 2003).

METHODS AND RESEARCH AREA

Aerial survey is made from Mil-8 helicopter by laser scanning set ALTM 2050 by Optech Inc., Canada. Video and photo scenes are recorded simultaneously by Sony DCR-PC110 megapixel mini DV camcorder with Carl Zeiss Vario-Sonar optics and KODAK DSC-EOC 1c digital camera with 5000×3000 pixel resolution CCD which provides 10 cm high on ground linear resolution from 300 m of flight altitude at about 300 m of scanning path width (Danilin et al., 2000; Medvedev, 2004; Medvedev et al., 2004).

The width of the patch covered in a single pass of aircraft depends on the scan angle of the laser system and the aircraft flight height. Typically operating specifications are at flying speeds of 200 to 250 kilometers per hour (55-70 meters per second), flying heights of 300 to 3,000 meters, scan angles from 0 up to 20 degrees, and pulse rates of 2,000 to 50,000 pulses per second. These parameters can be selected to yield a measurement point every few meters, with a footprint of 10 to 15 centimeters, providing enough information to create a

digital terrain (DTM) and forest vegetation model adequate for many forestry and forest engineering applications, including the design of forestry operations, projecting and alignment of forest roads, the determination of timber stock and volumes of ground works, and the design of harvesting schemes and structures.
The position of the aircraft at the time of each measurement is determined by phase difference kinematic Global Positioning System (GPS). Airborne and ground based GPS receivers Ashtech Z-12, Ashtech Z-Field Surveyor, Ashtech Z-Surveyor are used for the laser airborne survey. Rotational positions of the beam director are combined with aircraft roll, pitch and heading values determined with an inertial navigation system, and the range measurements to obtain vectors from the aircraft to the ground points. When these vectors are added to the aircraft locations they yield accurate coordinates of points on the surface of the terrain. Uncertainty of one-time measurement of geographical coordinates using ALTM-2050 machine and Ashtech GPS does not exceed 0.1% of flight height.
Laser sensing data and digital video images and photographs are examining for quality and preprocessing at once on board of aircraft and later on ground using special software which allow to get geometric parameters and highly accurate coordinates of separate trees and well readable morphostructural characteristics of forest canopy along the flight course.
All images and database are presented at three-dimensional (3D) view as customers may work with digital terrain model (DTM) and video- and photographs at more comfortable regime.
At 2003 general methodology of forest cover mapping and stand structure interpreting by ALTM-2050 machine was studied and developed. The research had been placed along 200 km flight and sampling transect at Turukhansk region of Krasnoyarsk krai, Central Siberia, within Bakhta river basin (right tributary of Yenisei river) (63-64°N, 91-92°E) at subzone of Siberian middle taiga dominated by larch (*Larix sibirica*) - spruce (*Picea obovata*) – Siberian pine (*Pinus sibirica*) forests in some sites mixed with birch (*Betula pendula*) and sphagnum bogs and wetlands.
For ground verification of aerial survey data 35 sample plots were established along the transect representing all dominating forest types and site environments. At the sample plots sample trees were selected, measured and cut down by 2 cm DBH and 1 m height range for stem analysis and stand phytomass assessment (Fig. 1).

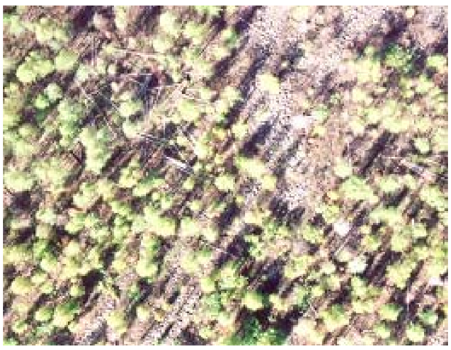

Figure 1. Aerial digital 15 cm on-ground linear resolution True Color photograph of larch (*Larix sibirica*) stand within laser scanning profile at Bakhta river basin in Central Siberia (63°34′47.3″N 90°42′11.2″E)

RESULTS AND DISCUSSION

Interactive processing of laser and digital photo data is implemented by original Altexis software, which has been designed for processing data of combined laser scanning and aerial photography.
ALTEXIS 2.0 provides metrological provisioning for aerial survey facilities including calibration procedures for LIDAR and digital cameras. It can also be used to monitor quality of piloting and assess reliability of collected aerial survey data. Besides ALTEXIS version 2.0 realizes a wide range processing algorithms of the data: generating DTM, geomorphological terrain analysis; creation of orthophoto, automatic selection of laser points, identification of geographical objects, modeling of power transmission lines, assessment of forestry engineering parameters and many other features. This is the next step on the way to the Real Time Mapping.
The new version of the ALTEXIS software features many significant advantages as compared to earlier versions:

- The user interface is organized in a basically new way. It's now much closer to the industry-adopted standards for the interfaces, which implement software package for processing geospatial data.
- Significant improvements have been made to the file structure where data are stored, for both the primary aerial photography data, and certain stages of data processing. These improvements cover both source aerial survey data. It allows to dispose the disk space much more economically, which is extremely considerable improvement due to the increasing productivity of the aviation laser-location systems and increased digital aerial photographs format.
- The updated algorithms of relief allocation based on laser scanning data considerably raises quality of the geomorphological analysis of a stage of supervision.
- The new technology of joint accumulation and laser scanning and aerial photography data processing is realized. The accuracy of automatic geopositioning of aerial photographs has been considerably increased.
- The full compatibility with previous versions ALTEXIS version 2.0 in data formats and mathematical device is provided (Fig. 2).

As a result of processing of the laser location data we get primary ground profile, which consist of vegetation and topographic (ground) surface profiles. Topographic surface is interpolated consequently by equalization and joining (unification) of points, where laser beam had reached the ground penetrating through tree crowns/leaves.
Eliminating topographic profile from the primary one we get forest vegetation/tree stand profile.
The analysis of forest vegetation and tree stand structure integrated with aerial digital photographic and video data allow to accurate interpretation of different types and layers of forest vegetation dividing it by tree species, density and other parameters.
Subsequent processing of the laser profiling data by means of integral calculations, Fourier and mean free path analysis make it possible to get such important and precise information on vegetation as timber stock, forest type, NDVI at a direct way or by mediate - on correlation with tree crown diameter, density, crown vertical extent and tree stand height (Fig. 3, 4).

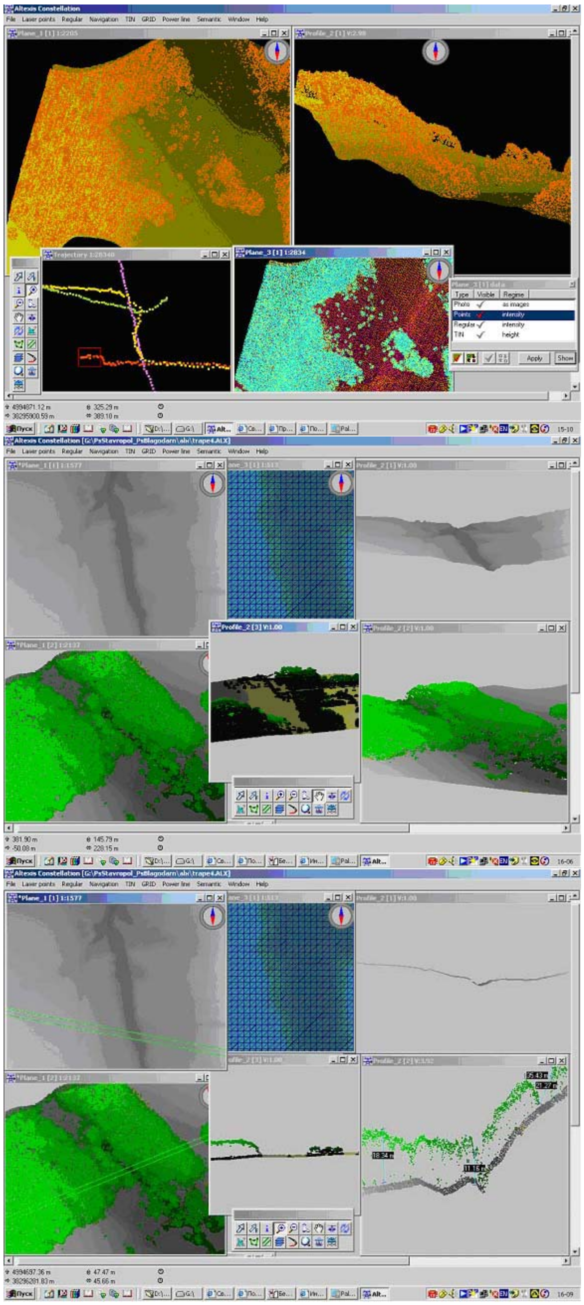

Figure 2. Visualization and complex geometric measurement of laser location data at Altexis 2.0 working window

The regression method provides high accuracy of stand biomass interpretation when processing a laser profiling data (Table 1, Fig. 5, 6).

The laser location survey method combined with high-resolution digital photography as well as on-ground and airborne GPS support allow remotely, operatively and with high accuracy to get information on forest cover condition and environment with a basic scope of data on surveyed object which may be a foundation for various thematic GIS compilations of different complexity. Such basic scope of data includes:

Accurate detailed description of terrain relief and creation of regular Digital Terrain Model (DTM) where relief is represented in its primary form not affected by forest vegetation.

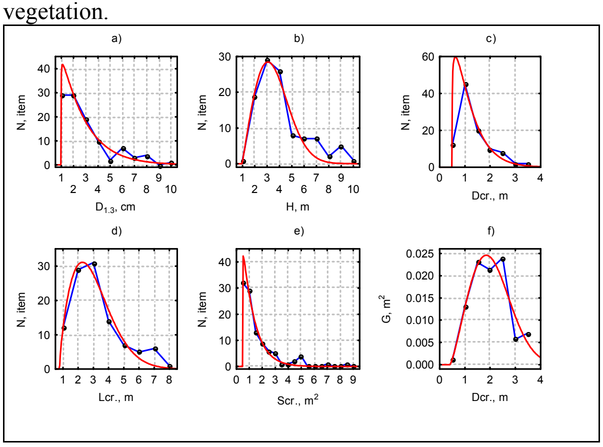

Figure 3. Empirical distribution lines for larch trees by morphometric indices of stems and crowns and approximated by Weibull distribution: a) - $D_{1.3}$, b) - H, c) - Dcr., d) - Lcr., e) - Scr., f) - G *f* (Dcr.)

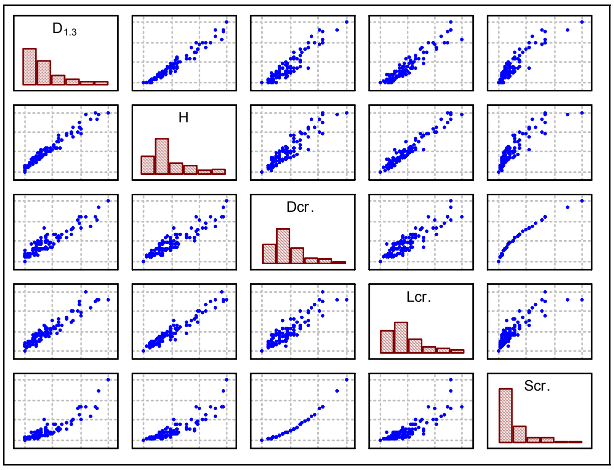

Figure. 4. Overlap matrix for distribution histogram and correlated scattering of the main morphometric indices of larch stand (Central Siberia)

Index	$D_{1.3}$	H	Dcr.	Lcr.	Scr.
$D_{1.3}$	1.00	0.98	0.93	0.95	0.91
H	0.98	1.00	0.92	0.96	0.89
Dcr.	0.93	0.92	1.00	0.90	0.97
Lcr.	0.95	0.96	0.90	1.00	0.87
Scr.	0.91	0.89	0.97	0.87	1.00
Average statistical	2.74	4.05	1.27	3.11	1.50
Standard deviation	2.03	1.92	0.56	1.66	1.45
Observations	205	205	205	205	205

Table 1. Correlation matrix (R) for morphometric indices of larch stand (Central Siberia)

Precise topologic models of natural and man-made facilities being objects of survey. Thus computer-aided contouring of forest management compartments, cuttings, burnings, roads, waters etc. (in absolute geodetic coordinates) and elevation there of, coordinates of trees and of the compartments' boundaries, intersections identified, relief cross section along route axis compiled, other significant objects allocated within a corridor of a required size along the survey route.

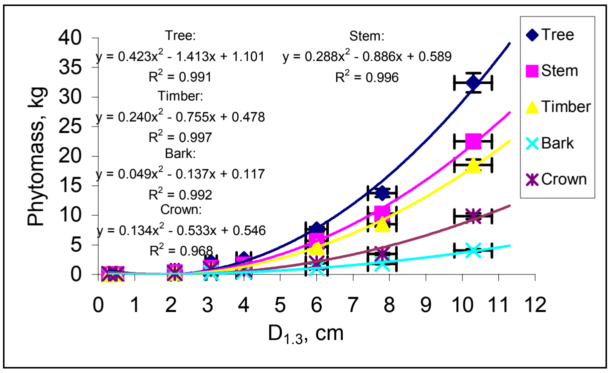

Figure 5. Aboveground phytomass/DBH correlation by fractions for sample larch trees (Central Siberia)

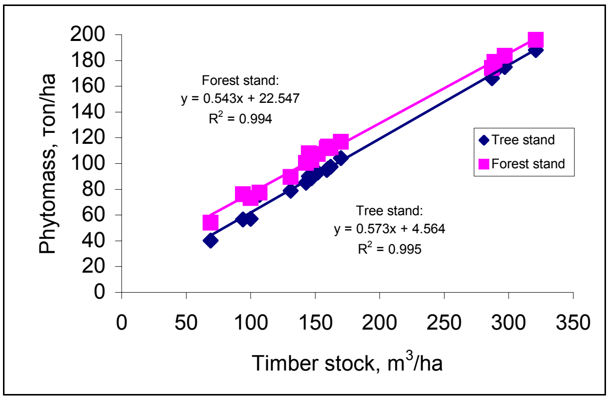

Figure 6. Aboveground phytomass/timber stock correlation of "Forest" and "Tree" stands within laser scanning profile at Bakhta river basin in Central Siberia (Krasnoyarsk territory)

Georeferenced digital aerial photos representing natural True Color image of survey object, with terrain resolution of 8-12 cm per pixel. Mandatory fixation of aerial photos exterior orientation parameters during survey (spatial coordinates of principal point, camera optical axis orientation angles) along with DTM created by laser locator allow all photogrammetric measurements on such photos, as well as automatic creation of digital orthophotoplans and photomaps on their basis.

The scope of collected data may be expanded in number of cases. Thus, the parallel IR survey performance appears necessary quite often. Classic examples are detection of forest fires sites' and measuring forest floor temperature at line survey, or control of thermal status of burning materials like timber residuals and wastes.

Another practically important addiction may be a multispectral scanner, which data is extremely useful in number of forest health and ecological applications. Utilizing of all such thematic sensors naturally fits the concept being implemented - availability of GPS facilities on board as an absolute time source and precise information on aircraft position during survey allows to only synchronize data of all such sensors with unified onboard time, after which during on-ground processing to mathematically apply aircraft evolution and perform geometric correction of thematic data. Practical implementation of such approach does not presume significant expenses as most of state-of-the-art airborne remote sensors produce signals that can be directly used for such synchronization, and necessary universal correction software has been developed.

Thus, the basic scope of data can be, if necessary, upgraded with one or several GIS thematic layers connected to the unified topographic base, without increase of aerial survey works, ensuring same strict methodology and metrology requirements.

CONCLUSION

Principal advantage of presented technology versus classic approach is explained by the following:

Only digital methods are used on all stages of collection, archiving and processing data, both on the aircraft and during ground based processing. As a result data processing starts in the landing point immediately after flight day.

One of major factors is a 3-D nature of obtained data. Application of laser locator allows to, firstly, immediately obtain 3-D image of terrain and all ground objects and perform geometric measurements on them, and, secondly, with no technological effort achieve any image detail resolution by choosing appropriate flight and survey regimes: altitude and speed, as well as width of swath coverage.

Thus, while ensuring practically unachievable by classic aerial topographic methods accuracy of DTM, laser location also shows the advantage of higher degree productivity for large scale topography survey of forested areas at about 100-150 кm, and on fixed-route flight survey about 500-600 km per day.

Besides, for number of cases the laser location appears the only possible source of information on forested lands:

True relief measurements (ground surface) without significant loss of accuracy is possible with laser location methods for open forest areas and even under tree canopies.

The work areas without visual texture is possible to survey like forest openings, sands, fully snowed areas etc.

Survey of location and shape of objects of a complex structure mostly man-made, for example forest plantations, power line towers and lines, buildings and facilities, etc.

The state-of-the-art aerial survey methods provide almost complete exclusion of ground geodetic works from technology cycle, as the data obtained principally at WGS-84 no need for plan/elevation on-ground support. The only exclusion is positioning and operating base GPS stations. At survey of extended objects, to ensure absolute geodetic accuracy of laser location and photo data of 15-20 cm such stations should be located with 100–150 km interval of each other. If accuracy requirements are not that strong this interval may be increased. Operation of GPS base stations does not require any special geodetic knowledge of operator and basically is limited to its locating in indicated place and switching power supply on (Medvedev, 2004).

The mostly principal and critical point is declining of the method's labor costs comparably to classic methods it is cheaper at more than two times in general (Danilin, 2003). Aerial laser survey equipment may be installed within one day to any light aircraft like Antonov-3 or helicopter Mil-8 with permanent cargo/survey hatch. This makes possible to use aircrafts of local aviation companies and enterprises at any region, eliminating high expenses of long distance driving of aircraft to a survey site.

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