LIDAR APPLICATIONS IN FORESTRY – AN OVERVIEW

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ABSTRACT

The objectives of this paper are to provide the interested reader with an overview of LIDAR applications in forestry and to summarize the current state-of-the-art. We discuss the history of LIDAR and early applications of LIDAR in forest mapping and inventory. As with most LIDAR applications, efforts to use LIDAR in a forestry context are new—1996 is an early citation. Our summary of LIDAR research focuses on, but is not limited to, two major conferences: the "International workshop on three-dimensional analysis of forestry structure and terrain using LIDAR technology" held at the Pacific Forestry Center in March, 2002 and the "ScandLaser scientific workshop on airborne laser scanning of forests" held in September, 2003 at the Swedish University of Agricultural Science. We also summarize current, on-going efforts as they were reported in a survey of LIDAR providers, researchers, and users conducted by the authors. Research in Europe, North America, and Australia is highlighted. An extensive bibliography including website citations is included.

INTRODUCTION

In October of 2001 the ASPRS and MAPPS jointly offered a conference entitled "Measuring the Earth—Digital Elevation Technologies and Applications". Had the conference been offered 5 years earlier, the attendees could expect primarily discussions of the developments in DEM-generation and editing through softcopy photogrammetry. But, new technologies were afoot. The proceedings, The DEM Users Manual, covered photogrammetry and four other competing technologies: topographic LIDAR, IFSAR, airborne LIDAR, bathymetry, and sonar. After attending the conference presentations and reading the proceedings, it was apparent that topographic LIDAR showed the greatest promise over forested areas.

Airborne laser profile systems were introduced in the 1970s and 80s, however, it is the commercial availability, supported by the new geo-positioning systems: global positioning systems (GPS), inertial measurement units (IMU), and inertial navigation systems (INS) that make airborne laser scanning systems practical (also referred to as airborne light detection and ranging or LIDAR systems). The commercial history of these scanning systems extends back into only the mid-1990s. From the perspective of a practicing forester, therefore, topographic LIDAR is new technology.

The forestry-related activity in airborne, small footprint laser scanning is well documented in the literature. Perhaps the best bibliography is maintained by Felix Morsdorf, on the Internet[1]. Most of the forestry-related references in Morsdorf's bibliography are covered by the keywords of forest stand, canopy, gaps, growth, inventory, or forest structure. There are 105 papers cited in this list as of this writing. Ninety-eight of these papers were published since 1999, with the vast majority appearing in the familiar remote sensing journals.

The Early Interest—Circa 1997

One of the striking facts apparent in any review of the LIDAR literature is the lead taken by the Europeans. As early as July 1999, the ISPRS organized and published a special LIDAR issue (ISPRS, 1999) that contained twelve papers. The lead paper was authored by Professor Friedrich Ackermann, a well-known photogrammetrist. Ackermann discussed the rapid technology expansion from the early laser "profiling" studies conducted at Stuttgart University (1988 to 1993) to the successful scanning systems available in 1999. In this same issue, Baltsavias (1999) listed 40 systems in operation at that time around the world: 16 in Europe, 12 in the US, 8 in Canada, 3 in Japan, and 2 in Australia.

The editors of the ISPRS special issue, referred to Professor Ackermann as the "pope" and initiator of LIDAR in the European community. In his paper, Ackermann mentions that his original motivation to study LIDAR was based on the need for DEMs in forested areas. In particular, he was interested in obtaining topographic data describing the forest floor under dense canopies. The Stuttgart studies showed canopy penetration rates of 20-40% in the typical coniferous and deciduous forests and 70% during the leaf-off winter months.

LIDAR was an immediate success for DEM generation and, as Ackermann acknowledged, it became a serious competitor to aerial photogrammetry for many mapping projects. Of course, there were problems.

The Early Problems—Research and Development Needs

In 1999 Ackermann proved to be something of a visionary in that he recognized both the great potential of LIDAR and many of the developments necessary to fully realize that potential. At that time he anticipated many of the technology improvements that were to come: increased pulse rates, refined electronic analysis, etc. (Baltsavias, 1999). He also listed several developments that would be needed to diversify and extend applications of the technology.

Intelligent data filtering. This problem was apparent from the start, particularly in a forested area. Whether the objective is a ground DEM or forest parameters, the first step is to filter the data to separate terrain and off-terrain laser reflections. Many people have worked this filtering problem, but Kraus and Pfeifer (1998) prepared perhaps the best early discussion. They proposed, implemented, and tested a method for filtering and processing LIDAR data to automatically identify the ground surface. As is normal with most filtering approaches, all goes well until the exceptions arise: the presence of unique geomorphology (ditches, slumps, riverbeds), and manmade structures (buildings, roads, and the likes) generally requires special editing.

More sophisticated object modeling. Both the Kraus and Pfeifer paper and another early report on topographic applications (Huising and Gomes Pereira, 1998) emphasized the need to augment the analysis and reduction of LIDAR data with an appreciation for geomorphologic structure, landscape modeling, city models, and/or the integration and comparison with existing databases such as those developed come from stereo-photographs. Several of the papers in the ISPRS special issue (Haala and Brenner, 1999; Maas and Vosselman, 1999) were devoted specifically to such approaches. Work to automate object recognition, modeling, and extraction continues.

Exploiting LIDAR in the world of GIS data acquisition. Certainly the initial LIDAR development was technology driven (Ackermann, 1999) through the convergence of the technologies involved (pulse laser, the scanner, GPS, IMU and INS), but one cannot ignore the commercial impact of the demand for DEMs coming from the GIS world. And, of course, the GIS communities' appetite for geospatial data does not stop with DEMs. Most everyone recognizes the huge market for LIDAR products that a technician can simply 'click and drag' directly into their favorite program. But, Ackerman warned, such products will require the development of standards to ensure operational reliability and quality in the data and its interpretation.

Data visualization. Ackermann saw in 1999, as most of us still see today a need for "additional image information" to lend a visual dimension to the geometry inherently captured by LIDAR data. Limited progress has been made in this area.

[1] http://www.geo.unizh.ch/rsl/services/bibliographies/lidar/

Effective fusion with photogrammetry. As many readers will know, Ackermann is a well regarded researcher in photogrammetry as well as LIDAR. In his opinion, "…it would be a complete revolution in photogrammetry if image data could directly be combined with spatial position data" (Ackermann, 1999). The most straight-forward approach would be the simultaneous capture of co-registered LIDAR data and digital imagery. Independent images could be co-registered through post-possessing but the result might not be as useful. In the forestry context where aerial photographs and other spectral data remain important, the effort to merge LIDAR with imagery is likely to be a large one.

Data collection, processing and delivery. This was not one of Ackermann's points, but it was given early emphasis by Huising and Gomes Pereira (1998), and remains an important point today. The quality and calibration of GPS and INS systems, the scanner adjustments, alignments, data redundancies, and the myriad of other system design and operational problems will be ever-present. The forestry community, which is at largely inattentive to the details of the source of the geospatial data it consumes, will be particularly vulnerable to the problems of poorly collected or processed data.

The Forester's (Early) Perspective on LIDAR Potential and Problems

In 1997, Erik Naesset, a Norwegian forest researcher who was experienced in the "current methods" of forest inventory, took advantage of an early application of airborne laser scanning in Norway[2]. Forestry data were not the primary objective, but Naesset examined LIDAR data collected over 36 forest stands for the important metric of mean tree height. Although the density of data was low with a return spacing from 2.8 to 3.3 meters, his observations were encouraging (Naesset, 1997a).

The delineated stands in Naesset's study ranged from 1 to 11 acres in size and his objective was to estimate the mean height of all overstory trees. He tried several metrics including: arithmetic mean of all LIDAR observations, mean of observations weighted by their own relative height and/or the square of their height, and a mean over a regular grid of cells with the height taken as the maximum LIDAR observation in each cell. The precision and accuracy of LIDAR as a tool for tree height and, potentially, tree count was immediately appreciated by Naesset. However, the question as to how to use the tool remained.

Naesett's early discussion pointed to the effects of nadir angle, beam footprint size, and data density on height predictions. However, the effects of canopy density, tree counts per area and species identification clearly needed additional research. Naesett showed that tree heights could be estimated using LIDAR data but a methodology to determine the ultimate goal, wood volumes, was not immediately apparent. However, it was clear from this early work that forest mensurationists clearly had new fertile ground for potentially rewarding research.

LIDAR Developments in Forestry—Pacific Forestry Center Meeting 2002

In March, 2002 the Pacific Forestry Center hosted the "International workshop on three-dimensional analysis of forestry structure and terrain using LIDAR technology." There were 80 forest researchers in attendance. Collectively, they represented most of the research and development activity underway in North America.

The Pacific Forestry Center meeting was followed up by a special issue of the Canadian Journal for Remote Sensing, entitled "LIDAR remote sensing of forest structure and terrain" (CJRS, 2003). The papers published in this issue encompassed a wide range of topics but can be grouped into three general themes:

- Terrain and geomorphological applications,
- Forest structure analysis,
- Individual tree analysis.

Terrain and geomorphological applications. Reutebuch et al presented an evaluation of the accuracy of a high-resolution LIDAR digital terrain model under varying canopy densities in the Pacific Northwestern United States. MacMillan *et al.* utilized a high resolution LIDAR-derived digital terrain model to analyze and classify geomorphic and hydrologic terrain features.

Forest structure analysis. Todd et al analyzed the relationship between horizontal and vertical distributions of light transmittance and foliage distributions using LIDAR in a sugar maple stand in northern Ontario, Canada. Weller *et al* described an approach to estimating forest structure parameters, including foliage projected cover and tree height, in southeast Queensland using laser profiler data. Lovell *et al.* evaluated the capabilities of ground-based and airborne laser systems for estimation of height, cover, and vertical foliage profile in New South Wales, Australia. Lim et al used LIDAR data to estimate biophysical properties, including 1) maximum tree height, 2)

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[2] FOTONOR A/S, Norway and Topscan GmbH, Germany collected and processed LIDAR data with an Optech ALTM 1020 scanner on several forestry projects in Norway as early as 1996. (See Naesset, ISPRS, 1997).

Lorey's mean tree height, 3) mean diameter, 4) total basal area, 5) percent canopy openness, 6) leaf area index, 7) ellipsoidal crown closure, 8) total aboveground biomass, 9) total wood volume, and 10) stem density in tolerant northern forests in Ontario, Canada. Gaveau and Hill evaluated the accuracy of a LIDAR-derived canopy height model in a hardwood forest in England. Holmgren *et al* used a simulation-based approach to investigate the effects of lidar scanning angle on estimation of mean tree height and canopy closure. Wulder and Seeman used a regression model to spatially extend a LIDAR-based survey of stand height from a sample to a larger area covered by Landsat imagery in Saskatchewan, Canada. Dowling and Accad incorporated LIDAR height data into the Specht structural vegetation classification to produce a map of vegetation height classes within Queensland, Australia.

Individual tree analysis. Popescu et al utilized LIDAR and multispectral optical data to identify individual trees and measure crown diameters for the purpose of estimating plot-level volume and biomass in the eastern United States. Leckie et al used a combination of multispectral and LIDAR data to improve automated recognition of individual tree crowns.

LIDAR Developments in Forestry—ScandLaser Scientific Workshop 2003

In September, 2003 the Swedish University of Agricultural Science hosted the "ScandLaser scientific workshop on airborne laser scanning of forests" (Hyyppa, J. et al, 2003). There were 70 forest researchers in attendance. Collectively, they represented most of the research and development activity underway in Europe. Presentations at this conference generally fell under 6 main themes:

- History and state-of-the-art in Scandinavia,
- System parameters, models and algorithms,
- Ecological applications,
- Change studies,
- Forest inventory applications,
- Single tree based methods.

History and state-of-the-art in Scandinavia. Naesset, Olsson, and Hyyppa described the status of LIDAR-related forest research and development in Norway, Sweden, and Finland, respectively.

System parameters, models and algorithms. Steinvall discussed some the new developments on the horizon in system development, including 3-D sensing focal plane arrays, ultra-short wavelength systems, and fusion of laser, radar and other sensors. Bollandsas introduced a partial least squares regression technique for modeling forest stand parameters using LIDAR, and compared these models to stepwise regression models. Gobakken and Naesset used a variety of LIDAR-derived metrics to estimate tree size distribution models in Norway.

Ecological applications. Several papers dealt with the application of LIDAR data to analysis of wildlife habitat and evaluation of LIDAR-derived canopy structure information. Hill et al used a LIDAR-derived height model to map woodland bird habitat in England. Sato et al utilized a LIDAR canopy height model to test the effects of forest type on wood mouse populations in Japan. In a project carried out in Bavaria, Heurich et al compared a LIDAR-derived canopy height model to field measurements.

Change studies. The acquisition of multiple LIDAR datasets over the same forest area in different years enables the analysis of forest growth. Sweda et al analyzed two LIDAR datasets acquired five years apart to investigate changes in vegetation due to climate change in an area of northern Saskatchewan, Canada. In Finland, Yu *et al* used LIDAR datasets acquired two years apart to investigate tree height growth.

Forest inventory applications. A number of papers presented methods for carrying out forest inventory and monitoring using LIDAR data. Nilsson and Holmgren evaluated data acquired with different footprint sizes and measurement densities for estimating tree height and stand volume in southern Sweden. Diedershagen et al described the objectives of the NADSCAN project at Freiburg, Germany, including estimation of variables such as tree age, stem diameter, height-diameter relationships, timber volume, and tree species distribution using LIDAR and digital imagery. Hirata et al presented an analysis of forest stratification and distribution of understory vegetation in Japan. In the Netherlands, Clement et al presented an approach to estimating 3-D forest stand properties, including volume, dominant tree height, basal area, and mean diameter using LIDAR. Using high density data acquired in Strelitz, Germany, Bottcher and Kleinn developed a methodology for estimating tree height, dbh, and stem density.

Single tree based methods. Several papers described recent developments related to measuring individual tree crown attributes from LIDAR data. Maltamo et al described research conducted in Finland where an approach was developed to model the distribution of small trees which are not typically detected though segmentation of a LIDAR height model. Brandtberg et al analyzed the influence of forest type on the implementation of an automated individual tree-based analysis of LIDAR data. In Sweden, Persson et al (2002) developed a technique for detecting, measuring and classifying individual trees using high density LIDAR data.

Where Do Foresters Go From Here?

"LIDAR is the best remote sensing instrument we have found so far for forestry applications". That is the assessment of Hakan Olsson, Professor in forestry remote sensing at the Swedish University of Agricultural Sciences (pers. com.). The general feeling among researchers is that LIDAR is such an incredible tool that its usefulness is obvious. The actual practical use so far, however, would seem to contradict this opinion.

Nearly every discussion in published articles devoted to tree height measurements (Naesset et al., 1997a), individual tree identification (Leckie et al., 2003; Persson et al., 2003), canopy structure assessment (Weller et al., 2003) or forest volume determinations (Popescu, et al, 2003; Naesset, 1997b) share the optimism—LIDAR provides the data necessary to measure forest vegetation. Similarly, discussions devoted to terrain modeling (Reutebuch et al., 2003), and the many applications for accurate high-resolution DTMs, relay an excitement about the prospects in forest engineering, hydrology, and geology. So, what about the actual applications?

Although numerous forest researchers are engaged in LIDAR research, it appears that there is a dearth of practical applications of LIDAR data in forestry. The Scandinavians sponsored a special session on "the Norwegian, Swedish, and Finnish Experience" in the 2003 Scandlaser meeting however, except for these discussions, there are no reports of large applications in the forestry literature.

A SURVEY ABOUT "LIDAR IN FORESTRY"

Although the body of literature on LIDAR research is large[3], there is scant reference to large-scale forestry applications. Still, we assume that some exist, and we've tried to identify them through by contacting data providers, researchers, and data users directly. Our mailing list, which we felt represented a large share of the "LIDAR in Forestry" community, was compiled through our collegial contacts and from the list of attendees at the 2002 Pacific Forestry Center and the 2003 ScandLaser meetings. Our questions were:

- Are you currently investigating a practical, forest-related application of LIDAR?
- Have you used, or are you currently using LIDAR in a forestry-related application?
- Are you aware of an ongoing, practical use of LIDAR in a forest application?
- What are your thoughts about the eventual use of LIDAR in forestry, the extent of that use, and your speculations about how LIDAR will most likely be used?

We received 14 responses by our deadline of January 31, 2004. While we were somewhat disappointed by the small number of responses, we were fortunate to receive responses from some of the foremost researchers in the field (see the list of respondents at the end of the paper). We felt the respondents provided current, mature, and well-considered responses to our questions. The following discussion presents the results of the survey organized by LIDAR providers, providers of LIDAR-derived products, and providers of forest inventories.

The Provider's View

"…after seven years experience of doing many different LIDAR surveys, it doesn't look like it'll be a big part of our workload in the near future" (Fowler, pers.com.) The community of forest companies can seem at times to be very stuck in their old, time-tested ways. They have a method for forest survey. They stratify the forest (most normally from aerial photographs) into similar stands, then collect the tree-specific information inside of well-distributed sample plots, and statistically extrapolate the data into an inventory-per-stand summary. The attitude is 'this suits us fine; until a cheaper method comes along, we're happy with our method, thanks'. In Fowler's experience, the bottom line, i.e. cost, still limits the forester's interest in LIDAR, and even at the contemporary level of 70 to 80 cents (US$) per acre for large projects, the majority of companies are not interested. Another respondent (MacMillan, pers.com.) felt that LIDAR will start to become attractive for DTM-generation at 38 cents per acre.

The View of Those Providing Other Products Such as Digital Terrain Models

Although the forest industry includes a very large group of GIS users, they have been generally satisfied with low-accuracy coordinates and rather coarse DTMs, namely the 30- by 30-meter or the 10- by 10-meter resolution models available from USGS and other sources. The thought of having a DTM with enough resolution and accuracy

[3] see the LIDAR bibliography at http://www.geo.unizh.ch/rsl/services/bibliographies/lidar/

to produce an accurate hydrologic map, a correct slope map, or terrain descriptions detailed enough to plan and design road systems in the office has been unthinkable prior to LIDAR.

Reutebuch et al. (2003) note that "…although we can conclude that high-density LIDAR is accurate enough to be of great benefit to forestry, the high cost is a concern. Even the relatively inexpensive photogrammetric mapping is often not justified today by many forestry operations. However, the potential for a DTM to locate small streams and gullies, high-erosion sites, and to provide for better road and harvest planning promises to justify a larger investment in mapping.

Another provider in our survey, sees great opportunity in "…the use of derivatives of elevation data as the main inputs for producing accurate and cost-effective maps of ecological spatial entities in forested areas of the province of BC [British Columbia, Canada]" (MacMillan, pers.com.). This potential was well-researched (MacMillan et al., 2003). Again, however, there was the comment about cost: "…the cost of acquiring and producing LIDAR DEMs will have to become not only competitive with traditional photogrammetric techniques, but will have to become lower."

The Provider of Forest Inventories

Just as Norwegians were some of the first to research LIDAR's potential as inventory data (Naesset and Bjerknes, 2001), they are also leading the way towards widespread applications (Aasland, pers.com.). It seems that Sweden (Olsson, pers.com.) and Finland (Uuttera, pers.com.) are seriously evaluating the application of some basic LIDAR tool as part of their national forest survey. However, only Norway is currently using LIDAR in their inventory program. Naesset (pers. com.) estimates that approximately 20% of their forested lands are being inventoried using LIDAR.

The Scandinavians have been faithful users of remote sensing in their forest inventories. Most recently, aerial photo interpretation and forest stratifications were accomplished on digital photogrammetric systems. Uniform forest stands are sampled on the ground (measurements include tree heights, diameters and basal areas) or from aerial photographs (measurements include heights, crown closure) and forest volumes are determined statistically (Naesset, 1995). This attention to and active use of remote sensing tools among their foresters and within their institutions may explain their early investigations into the use of LIDAR (Nilsson, 1996; Naesset, 1997b).

Today, there are two large commercial LIDAR-based inventory projects in Norway: a 25,000 acre area near Oslo and a 60,000 acre area further north. Both areas have aerial photo coverage (1:15,000 and 1:18,000, respectively) and LIDAR data acquired at a density of one point per square meter. Ground sample plots (100 and 120 locations, respectively) have also been measured. The inventory is being conducted by Prevista Ltd[4], a forest planning organization that has developed their methods to service more than 2,000 forest owners at an annual rate of 500,000 acres of spruce and pine plantations per year (Tord Aasland, director of forest planning, pers.com. See also their ScandLaser presentation website[5]). Prevista has chosen to use LIDAR to augment and/or supplant a subset of the current inventory activity. This is occurring in several ways:

- The process of forest stand stratification with stereo-photographs on a digital workstation remains. However, height measurements from LIDAR are superimposed on the imagery,
- The incorporation of LIDAR-derived metrics into the digital photo interpretation enhances the value of the field plot data as well. The improved geo-referencing of all three datasets: LIDAR, photos, and field data facilitates a two-stage sampling process. Correlations between the LIDAR and field metrics (as recommended by Naesset and Bjerknes, 2001) are constantly improved and the number of field plots per stand are reduced and supplanted with LIDAR data,
- Finally, an obvious benefit is derived from the LIDAR coverage across an entire stand. Whereas the plot sampling approach would not reveal the full variation across a stand, the inference from the LIDAR regressions does.

The ultimate advantages of LIDAR in forestry are apparent in the results of Prevista's effort. As they note, "wood volume" is what they wish to correctly estimate, and "it can be compiled… and expressed in many different ways" (Tord Aasland, pers.com.). Their list of LIDAR derived metrics and products includes:

- Tree volume/ha,
- Numbers of stems/ha,
- Dominant height,

[4] The use of commercial names is for the convenience of the reader and does not imply any endorsement by the USDA Forest Service or the University of Washington.

[5] http://www.prevista.no/nyheter/pres/Scandlaser_2003-filer/frame.htm

- Mean height,
- Mean diameter,
- Bare ground DTMs.

Because of their anticipated reduction in the amount of fieldwork, they project only a slight increase (2.4%) in the total cost of their inventory (again, see their ScandLaser presentation website[6] for additional information). This increase covers the cost of acquiring LIDAR data and producing forest metrics, digital map layers, and the much improved DTM.

A Comment about the Forestry User Groups

Generally, there are two customer groups for LIDAR in the forest industry: the engineers, hydrologists, and geologists charged with planning and providing access for logging, and those foresters concerned about the inventory and monitoring of the trees. Although these groups operate within the same company or agency, they are often far apart administratively. LIDAR can provide products for both, but unfortunately the idea of sharing the cost of data acquisition and processing has been lost on many leaders of the larger bureaucracies. "LIDAR must be seen as something that will integrate across operational information needs, from engineering through to inventory" (Wulder, pers.com.). However, as the improved DTM and forest metrics are considered, the first uses are sure to be for products that "either augment or supplant a subset of current activities" (Wulder, pers.com.) and forest inventories are likely to be first.

Respondents to the "LIDAR in Forestry Survey"

The following individuals responded to our survey:

Individual	Affiliation	Country
Robert Fowler	Lasermap Image Plus/GPR	Canada
R.A.MacMillan	LandMapper Env Soln Inc	Canada
Benoit St-Onge	University of Quebec	Canada
Richard Reynolds	Forest Engineering Research Institute	Canada
Paul Treitz	Queen's University	Canada
Mike Wulder	Canadian Forest Service	
Hakon Olsson	Swedish University of Agricultural Science	Sweden
Erik Naesset	Norwegian University of Agricultural Science	Norway
Roland Wack and Mathias Schardt	Joanneum Research	Austria
Ross A. Hill	Centre for Ecology and Hydrology	United Kingdom
Jenny Lovell	CSIRO	Australia
Bernd-Michael Straub	University of Hannover	Germany
Janne Uuttera	Forestry Development Centre Tapio	Finland
Tore Aasland	Prevista AS	Norway

CONCLUSION

Understandably, in their response to our survey, Prevista concludes "…that Airborne Laser Scanning will be one of the most important methods for collecting data for forest resource management" (Tord Aasland, pers.com.). Put most simply: **We concur.**

SELECTED LIDAR-RELATED WEBSITES

Like many subjects today, the web is awash with information on the subject. We have found the information available at the following websites useful in compiling this paper and for researching LIDAR applications in forestry (sites were last visited February 3, 2004):

- **The LIDARtalk chatboard:** A discussion board launched by Martin Flood early in 2003 to encourage informal, unmoderated discussion of all matters related to LIDAR mapping technology, particularly the

[6] http://www.prevista.no/nyheter/pres/Scandlaser_2003-filer/frame.htm

ASPRS LIDAR committee efforts and activities. The topics range from "the best" scan patterns to who bought which LIDAR company and why. The site provides a good pulse of the LIDAR industry's activities. (http://www.LIDARcentral.com/LIDARtalk/wwwboard.shtml).

- **The ASPRS LIDAR committee:** A site sponsored by the ASPRS to publish the activities of their LIDAR committee. The site contains a description of who they are and what they are doing. (http://www.asprs.org/asprs/society/committees/LIDAR/LIDAR_frame.html).
- **The Puget Sound LIDAR Consortium:** A site that makes available data and information about the LIDAR activities around Puget Sound in the Washington state. This site provides a good example of the extent of coverage in some regions. (http://duff.geology.washington.edu/data/raster/LIDAR/).
- **The UW Precision Forestry Cooperative:** Two sites that describe some of the LIDAR research being conducted by the authors of this paper. (http://www.cfr.washington.edu/research.pfc/JFSP/ and http://www.cfr.washington.edu/research.pfc/).
- **Airborne laser mapping – a LIDAR provider's newsletter**: An industry site including an "Industry Directory" containing contact information for most LIDAR providers, a "Research Directory", and Industry News and Notes. This site provides a good overview of the extent of the LIDAR industry. (http://www.airbornelasermapping.com/).
- **Airborne laser scanning for forest research:** A site initiated after the 2003 ScandLaser meeting in Sweden to promote the timely dissemination of forest research and to facilitate the formation of international research networks. The site has been slow to get fully implemented, but it promises to be important to researchers studying LIDAR applications in forestry. (http://www.alsfor.org/index.html).
- The site for Canadian LIDAR industry and research activities. (http://home.cogeco.ca/~chopkinson/c_clear/).
- **Mississippi State Remote Sensing Technology Center**. A site describing various remote sensing research efforts in forestry and wildlife managment at Mississippi State University. (http://www.rstc.msstate.edu/fwmain.html).

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