LiDAR Applications for Transportation Agencies

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Request for Report
Light Detection and Ranging, or LiDAR, is a remote sensing technology that measures distances using reflected laser light (analogous to radar and radio waves or sonar and sound waves). Transportation agencies in the United States and worldwide have increasingly used LiDAR data collection systems, often in multisensor configurations that include global positioning systems, photography and video, for various applications.

WisDOT’s LiDAR Focus Group is assessing the most promising uses of LiDAR for the department. This Transportation Synthesis Report represents an initial scoping of LiDAR and its applications for transportation. Based on input from the LiDAR Focus Group, it will be followed by a survey of state DOTs on specific practices of interest to Wisconsin.

Summary
This report provides selected resources that describe the Principles of LiDAR and the three Types of LiDAR: airborne, mobile and terrestrial. LiDAR Applications of interest to transportation agencies include surveying, highway design, corridor development, critical infrastructure protection, traffic flow, highway safety, and rock cuts and geology. Three key Technical Issues that are the topic of continued research are data collection and analysis, error and accuracy, and the integration of LiDAR and photogrammetry. Finally, several organizations, conferences and journals are useful Resources for further information.

Principles of LiDAR
The following presentations provide a detailed technical background on how LiDAR works.

“LiDAR Remote Sensing Overview”
Presentation by Xinzhao Chu, University of Colorado, 2007
http://superlidar.colorado.edu/Classes/Lidar2007/Lecture03.pdf
This lecture for the graduate-level course “LiDAR Remote Sensing” offered at the University of Colorado includes a history of modern LiDAR and the basic architecture of LiDAR. Lecture notes and presentations for the entire course are available at http://cires.colorado.edu/science/groups/chu/classes/lidar2007.
“LiDAR Technology Overview”
This presentation describes the physical principles and underlying mathematical formulas behind LiDAR. It also provides details on the various sources of error in LiDAR.

Types of LiDAR
LiDAR is used for scanning and measurement in three different configurations: airborne, mobile and terrestrial. Airborne LiDAR (airborne laser scanning, or ALS) involves affixing the scanning hardware to an aircraft, which can be a fixed-wing craft or rotary-wing helicopter. For mobile LiDAR (mobile laser scanning, or MLS), the scanning hardware is mounted on a moving ground vehicle, such as a van, truck or train. Terrestrial LiDAR (terrestrial laser scanning, or TLS) involves a stationary ground scanning unit.

Selected resources on each of the three types of LiDAR follow. Specific uses of LiDAR follow in the next section of this Transportation Synthesis Report, “Applications.”

Airborne LiDAR

“Aerial Laser Scanning”
Presentation by Claus Brenner, Institute of Cartography and Geoinformatics, University of Hannover, Germany, 2006
The main points of this presentation are airborne laser scanning principles, errors and strip adjustment, filtering of ALS data, and extraction and modeling.

“Airborne LiDAR Sensors”
GIM International, February 2009
This article compares the specifications for 11 different models of airborne LiDAR sensors, comparing 42 different parameters in seven categories.

Mobile LiDAR

“Kinematic Terrestrial Light-Detection and Ranging System for Scanning”
Craig Glennie, Transportation Research Record, No. 2105, 135–141, 2009.
Citation at http://pubsindex.trb.org/view.aspx?id=880526
Abstract: Highway corridor surveys are becoming more difficult and expensive to carry out because of the need to minimize lane closures, traffic disruptions, and safety hazards posed to the surveyors and public. Roadway surveyors are at risk when working in the traffic corridor if they are unable to move with the flow of traffic. Safety for the traveling public is also a concern when lanes are closed or blocked by slow-moving vehicles. Costs for the placement of safety features to protect a survey crew can in some instances be greater than the cost of the survey itself. To mitigate these problems, a survey data acquisition tool is needed that can collect topographic and infrastructure information without disrupting traffic flow. Terrapoint has developed a novel kinematic laser scanning system that can be deployed on a passenger vehicle or small watercraft. Light-detection and ranging (LiDAR) digital imagery and video are collected from the survey platform while it is moving at traffic speeds. The system is georeferenced with a high-accuracy Global Positioning System–inertial measurement unit. Terrapoint’s mobile LiDAR scanner has successfully surveyed existing highway corridors all over North America. It has also proven sufficiently accurate for scanning airport runway surfaces so as to predict areas where water will pool. Moving with the traffic flow and not requiring an escort, the system scans a 360° swath that includes the pavement surface and objects to the sides and above the survey vehicle.

Survey of state DOTs on mobile laser scanner use, June 2009
http://research.transportation.org/Pages/MobileLaserScannerSurvey.aspx
Minnesota DOT conducted a survey of state DOTs through the AASHTO Research Advisory Committee in order to learn “which DOTs are seriously considering an investment in this technology or have already
“Geometric validation of a ground-based mobile laser scanning system”
Citation at [http://linkinghub.elsevier.com/retrieve/pii/S0924271607000834](http://linkinghub.elsevier.com/retrieve/pii/S0924271607000834)

Abstract: This paper outlines a study, carried out on behalf of a national mapping agency, to validate laser scanned point cloud data collected by a ground-based mobile mapping system. As the need for detailed three-dimensional data about our environment continues to grow, ground-based mobile systems are likely to find an increasingly important niche in national mapping agency applications. For example, such systems potentially provide the most efficient data capture for numerical modeling and/or visualization in support of decision making, filling a void between static terrestrial and mobile airborne laser scanning. This study sought to assess the precision and accuracy of data collected using the StreetMapper system across two test sites: a peri-urban residential housing estate with low density housing and wide streets, and a former industrial area consisting of narrow streets and tall warehouses. An estimate of system precision in both test sites was made using repeated data collection passes, indicating a measurement precision (95 percent) of between 0.029 m and 0.031 m had been achieved in elevation. Elevation measurement accuracy was assessed against check points collected using conventional surveying techniques at the same time as the laser scanning survey, finding RMS errors in elevation in the order of 0.03 m. Planimetric accuracy was also assessed, with results indicating an accuracy of approximately 0.10 m, although difficulties in reliably assessing planimetric accuracy were encountered. The results of this validation were compared against a theoretical error pre-analysis which was also used to show the relative components of error within the system. Finally, recommendations for future validation methodologies are outlined and possible applications of the system are briefly discussed.

Terrestrial LiDAR

**Photogrammetry & Remote Sensing: 3-D Terrestrial Laser Scanning**
Washington State DOT Web site
[http://www.wsdot.wa.gov/mapsdata/photogrammetry/3DTL.htm](http://www.wsdot.wa.gov/mapsdata/photogrammetry/3DTL.htm)

*From the site:* “WSDOT Geographic Services uses 3-D Terrestrial Laser Scanning technology to produce very accurate, very dense 3-dimensional digital data sets (called ‘point clouds’) used for CAD mapping. This technology is a fast, safe, and efficient way to model and measure many areas where it can provide advantages over traditional survey or photogrammetric methods. The WSDOT Geographic Services Photogrammetry & Remote Sensing Branch and Geodetic Survey Branch are highly skilled and experienced in this advanced technology. The Geodetic Survey crew scans the project while the Photogrammetry staff processes the data to the final 3D CAD deliverables.”

**“3D Terrestrial Laser Scanning as a New Field Measurement and Monitoring Technique”**
Citation at [http://www.springerlink.com/content/cnpe4fb46crd161f](http://www.springerlink.com/content/cnpe4fb46crd161f)

Abstract: 3D terrestrial laser scanning is a relatively new, but already revolutionary, surveying technique. The survey yields a digital data set, which is essentially a dense “point cloud,” where each point is represented by a coordinate in 3D space. The most important advantage of the method is that a very high point density can be achieved, in the order of 5 to 10 mm resolution. In order to analyze the character and shape of the scanned surfaces it is necessary to convert the irregularly distributed point data into 3D surface information using surface reconstruction. The reconstructed surface can subsequently be visualized using a variety of 3D visualization techniques. From the reconstructed 3D surfaces, it is also possible to generate 2D profiles or elevation contour lines for use in regular GIS or CAD packages. A number of applications are described in this paper, which may illustrate the possible benefits of using laser scanning as a technique in engineering geological practice and research: volume analysis and monitoring, detailed and large-scale topographic mapping, tunneling, rock face surveying, and digital outcrop mapping.
Applications
LiDAR is used in a wide range of transportation applications. For example, Wisconsin DOT described its use of airborne LiDAR in response to a 2009 survey conducted by the California Department of Transportation. As reported by WisDOT’s Kimberly Schauder, responding with Cindy McCallum and Tiffany Novinska:

“WisDOT has contracted for two LiDAR projects (in 2003 and 2004) that were supplemented with photogrammetric breaklines to meet +/- 0.3 feet root mean squared error (1 sigma = 67 percent confidence) design standards. One was flown at 1,500 and 3,300 feet above ground level (for comparison) and the second was 2,500 feet above ground level. Two base stations operating at 1-second collection rate along a 2-mile project and a 17-mile project.

“The results met specifications, but projects were not large enough for LiDAR to be a cost-effective solution over conventional photogrammetry. WisDOT has not contracted for LiDAR to supplement digital (and analytical compilation) methods.”

As another example, Ohio DOT listed three “LiDAR Innovations in Ohio” in the 2008 AASHTO Research Advisory Council publication of research highlights (http://on.dot.wi.gov/wisdotresearch/database/reports/racregion3highlights2008.pdf; see page 31). An excerpt:

Ohio DOT sponsored three separate research projects to further our understanding and usage of LiDAR.

Extensive simulations were performed in the project “Geo-Referenced Digital Data Acquisition and Processing System Using LiDAR Technology” (completed in February 2006) to determine a favorable LiDAR target design, including optimal target size and shape, signal response, coating pattern, and methods to accurately determine the 3-dimensional target position in the LiDAR dataset.

The project “Airborne LiDAR: A New Source of Traffic Flow Data” (completed in October 2005) demonstrated that LiDAR may be used to collect significant amounts of data rich in traffic flow information at almost no additional cost.

The project “Airborne LiDAR Reflective Linear Feature Extraction for Strip Adjustment and Horizontal Accuracy Determination” (concluding in June 2008) was initiated to better determine horizontal accuracy using existing linear features such as pavement lane lines. Results to date have shown much higher horizontal accuracies (within 4 inches) than previously thought possible.

Our search identified transportation-related LiDAR applications using one or more of the three types of LiDAR (airborne, mobile and terrestrial) in the following areas:

- Surveying
- Highway design
- Corridor development
- Incident management and critical infrastructure protection
- Traffic flow
- Highway safety
- Rock cuts and geology

To illustrate the issues and technologies surrounding these applications, we have provided one or two sample citations for each.

Surveying


Abstract: A typical highway project generally takes 5 years or more from planning phase to construction stage, particularly in wooded and difficult terrain using traditional topographic terrain mapping methods. This paper
presents an application of airborne laser terrain mapping technology for a 9-km (5.9 mi.) long highway project in a difficult densely wooded terrain with steep slopes and ravines. Elevation data accuracy, efficiency, and cost effectiveness were compared with the traditional aerial photogrammetry and ground-based total station survey methods. The elevations of centerline and 15 different cross sections were compared with groundtruthing data from the total station survey. Using appropriate flight mission parameters, the airborne laser technology permits elevation accuracy of 0.13 m (5 in). There are less operating constraints which adversely affect the productivity of traditional methods, such as cloud and vegetation cover, time of day, and intrusion into private properties. It is recommended to combine the low-altitude airborne laser technology with centerline staking by total station survey and aerial photography. The recommended combined approach saves 33 percent of the budget and 35 percent of time.

“Survey from Sanborn Terrestrial and Aerial LiDAR: Case Study for Illinois Department of Transportation (IDOT)”
http://www.sanborn.com/Pdfs/2009_whitepaper_GroundLiDAR.pdf
This corporate white paper from Sanborn Imagery Services describes the combination of traditional surveying, terrestrial LiDAR, airborne LiDAR, and terrestrial photogrammetry that the company created for the Illinois Department of Transportation.

Highway Design

“Integration of Light Detection and Ranging Technology with Photogrammetry in Highway Location and Design”
David Veneziano, Reginald Souleyrette and Shauna Hallmark, Transportation Research Record, No. 1836, 1–6, 2003.
Citation at http://trb.metapress.com/content/72n2820pt40482uh/
Abstract: Surface terrain information is needed to economically site new or relocate existing infrastructure facilities and make final design plans. Field surveying and photogrammetric mapping are the methods most widely used to acquire these data. However, these methods are time- and resource-intensive, as significant data collection and reduction are needed to provide the level of detail necessary for facility location and design. Light detection and ranging (LIDAR) is a relatively new alternative technology for obtaining terrain information more efficiently. With LIDAR, data can be collected under a variety of environmental conditions, including low sun angle, cloudy skies, and even darkness, resulting in expanded windows for data collection. Although less accurate than photogrammetric mapping, LIDAR can help expedite the highway location and design process by providing designers with preliminary terrain information earlier in the process. Presented is a proposed methodology for using LIDAR in conjunction with photogrammetric mapping to speed up highway location and design activities, including estimates of time and cost savings.

Grade and Cross Slope Estimation from LIDAR-Based Surface Models
http://www.ctre.iastate.edu/mtc/reports/LIDAR_Grade.htm#_Toc62447282
From the executive summary: This report discusses the use of LIDAR to extract roadway grade and cross slope for large-scale inventories. Current data collection methods and their advantages and disadvantages are discussed. A pilot study to extract grade and cross slope from a LIDAR data set, including methodology, results, and conclusions, is presented. This report describes the regression methodology used to extract and evaluate the accuracy of grade and cross slope from three-dimensional surfaces created from LIDAR data. The use of LIDAR data to extract grade and cross slope on tangent highway segments was evaluated and compared against grade and cross slope collected using an automatic level for 10 test segments along Iowa Highway 1. Grade and cross slope were measured from a surface model created from LIDAR data points collected for the study area. While grade could be estimated to within 1 percent, study results indicate that cross slope cannot practically be estimated using a LIDAR derived surface model.
Corridor Development

“Corridor Location: The Gateway Shortest Path”
An excerpt:

Corridor location software traditionally has two components: Calculating the “cost” of a given path through a cost matrix, and optionally, finding an optimal path that minimizes this cost.

Decision support systems should generate alternatives for consideration that are not only very similar to other paths under consideration, but also some that are very different spatially, while achieving comparable goals in terms of cost minimization. Proposed paths that have generated conflict and strong emotions can then be reconfigured completely, without significantly sacrificing their logistical benefits.

Researchers at the University of California, Santa Barbara developed the Gateway Shortest Path Problem (GSPP) approach, which finds spatially different alternatives by selecting “gateway” cells and computing shortest paths that pass through those gateways. The further the gateway cells are from the optimal path, the more likely it is that the gateway path will be significantly spatially different from the optimal path. The result is usually a good alternative in terms of cost since it is after all a shortest path, albeit constrained.

Suitability scores are derived from attribute data collected through LIDAR, multispectral sensing, and other methods. For more details on this research, see http://www.ncgia.ucsb.edu/ncrst/research/gateway/first.html.

Critical Infrastructure Protection

Spatial Information Technologies in Critical Infrastructure Protection: A Research Agenda in CIP
This report defines critical transportation infrastructure, outlines the threats to critical transportation infrastructure and the associated information needs to protect it. It describes the role of remote sensing technology, including LiDAR, in protecting critical transportation infrastructure.

Traffic Flow

“Vehicle Classification and Traffic Flow Estimation from Airborne LiDAR/CCD Data”
http://www.springerlink.com/content/g0428g0257n18lv9/
From the abstract: This paper provides a review of a 3-year research program on the feasibility of using airborne LiDAR (Light Detection and Ranging) and imagery collected simultaneously over transportation corridors for estimation of traffic flow parameters such as: (1) vehicle counts, (2) vehicle classification, (3) velocity per vehicle category, and (4) intersection movement patterns.

“Traffic Monitoring from Airborne LiDAR—Feasibility, Simulation and Analysis”
http://isprsrev.ifp.uni-stuttgart.de/congresses/beijing2008/proceedings/3b_pdf/110.pdf
Abstract: Automatic acquisition and analysis of traffic-related data has already a long tradition in the remote sensing community. Similarly airborne laser scanning (ALS) has emerged as an efficient means to acquire the detailed 3D large-scale DSMs. The aim of this work is to initialize research work on using ALS to extract the traffic-flow information focusing on urban areas. The laser data acquisition configuration has firstly to be analyzed in order to obtain the optimal performance with respect to the reconstruction of traffic related objects. Mutual relationships between various ALS parameters and vehicle modeling in the laser points are to be elaborated. Like other common tasks in object recognition, vehicle models for detection and motion indication from the laser data are presented; moreover, an ALS simulator is implemented to clarify and validate motion
artifact in laser data. Finally, a concept for recognizing vehicles are proposed based on a vehicle and context model, which establishes a direct working flow simulating the human inference routine.

Highway Safety

“Application of Light Detection and Ranging Technology to Highway Safety”
Citation at http://trb.metapress.com/content/f484678w2201n112/
Abstract: An application of light detection and ranging (LIDAR) technology to highway intersection safety is presented. LIDAR can be used to collect information about a surface by reflecting thousands of light beams per second off the surface and measuring the return time of the beams. The surface profile is collected as a digital signature that can be used in a variety of applications. Collection of information on the surface profile of the earth in the form of elevation data is one of several LIDAR applications that have been used for mapping and contouring. The focus of the described application is use of LIDAR elevation data to obtain information on intersection geometry that can lead to the discovery of potential obstructions in driver sight lines. After appropriate transformations, LIDAR elevation data were used in line-of-sight analysis to obtain information on sight-line obstructions at six intersections on the IA-1 corridor in Iowa. Intersection crash frequency and data availability were considerations in the selection of the six intersections. Results from the line-of-sight analysis were validated by visits to the intersections in the field and verification of the existence of obstructions detected during the analysis. Sixty-six lines of sight were blocked during the line-of-sight analysis, of which 62 (89.8 percent) were confirmed during the validation process. Four (5.8 percent) sight-line obstructions were not confirmed during the validation. At least three (4.4 percent) potential sight-line obstructions discovered during validation were not detected during the line-of-sight analysis. The intersection with the highest crash frequency was correctly found to have obstructions located within the intersection sight triangles. It can be concluded that LIDAR elevation data can be used successfully for identifying potential sight-distance problems at intersections. Identified potential problems can be verified and rectified in the field. LIDAR is a relatively costly data source, and a single application, such as this one, cannot justify the high cost of LIDAR data acquisition. Other potential highway safety enhancing applications of LIDAR must be investigated to offset the high data-acquisition cost. Suggestions for other highway safety applications are provided.

Rock Cuts and Geology

“Engineering Monitoring of Rockfall Hazards Along Transportation Corridors: Using Mobile Terrestrial LiDAR”
Citation at http://adsabs.harvard.edu/abs/2009NHESS...9..935L
Abstract: Geotechnical hazards along linear transportation corridors are challenging to identify and often require constant monitoring. Inspecting corridors using traditional, manual methods requires the engineer to be unnecessarily exposed to the hazard. It also requires closure of the corridor to ensure safety of the worker from passing vehicles. This paper identifies the use of mobile terrestrial LiDAR data as a complement to traditional field methods. Mobile terrestrial LiDAR is an emerging remote data collection technique capable of generating accurate fully three-dimensional virtual models while driving at speeds up to 100 km/h. Data is collected from a truck that causes no delays to active traffic nor does it impede corridor use. These resultant georeferenced data can be used for geomechanical structural feature identification and kinematic analysis, rockfall path identification and differential monitoring of rock movement or failure over time. Comparisons between mobile terrestrial and static LiDAR data collection and analysis are presented. As well, detailed discussions on workflow procedures for possible implementation are discussed. Future use of mobile terrestrial LiDAR data for corridor analysis will focus on repeated surveys and developing dynamic four-dimensional models, higher resolution data collection. As well, computationally advanced, spatially accurate, geomechanically controlled three-dimensional rockfall simulations should be investigated.
“Close-Range Terrestrial Digital Photogrammetry and Terrestrial Laser Scanning for Discontinuity Characterization on Rock Cuts”
Citation at [http://linkinghub.elsevier.com/retrieve/pii/S0013795209000556](http://linkinghub.elsevier.com/retrieve/pii/S0013795209000556)

Abstract: This paper reviews the application of close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. Terrestrial remote sensing techniques are being increasingly used as a complement to traditional scanline and window mapping methods. They provide more comprehensive information on rock cuts, allow surveying of inaccessible outcrops, and increase user safety. Selected case studies are used to estimate the accuracy of several 3D model registration approaches and the most time-, effort-, and cost-effective methods are highlighted. It is shown that simple registration networks are able to provide adequate measurement of discontinuity orientation for engineering purposes. The case studies presented also illustrate the effects of sampling bias and limitations related to discontinuity characterization using remote sensing techniques. Vertical orientation bias and occlusion can be of particular concern when persistent discontinuities dip at the same angle as the camera/scanner line-of-sight. Major advantages of the techniques are presented illustrating how terrestrial remote sensing techniques provide rapid spatial measurements of discontinuity location, orientation, and curvature and are well suited to the quantification of persistence magnitudes greater than 3 m.

**Technical Issues**
Researchers continue to address technical issues surrounding LiDAR. Given the large volumes of data to be collected, processed, analyzed, and interpreted, it is not surprising that significant research has been conducted on **Data Collection and Analysis**. In addition, researchers are focused on **Error and Accuracy** issues to promote useful and accurate results from LiDAR data collection. Finally, the **Integration of LiDAR and Photogrammetry** has proved to be a fruitful approach in creating useful data for transportation agencies.

Below we highlight selected research from each of these three areas.

**Data Collection and Analysis**

“Analysis and Integration of Spatial Data for Transportation Planning”

Abstract: Transportation planning requires substantial amounts of data and cooperation among transportation planning agencies. Advances in computer technology and the increasing availability of geographic information systems (GIS) are giving transportation planners the ability to develop and use data with a much higher degree of efficiency. However, as information systems advance, the need to provide effective data integration/exchange protocols and procedures to reduce redundancy and data collection costs is becoming more important. Many factors influence the effectiveness of data exchange and data integration efforts, such as data compatibility, data access, data quality, completeness, metadata, hardware, software, and staff expertise. This research resulted in a catalog of spatial data sources available to transportation planning agencies in Texas. The work included a synthesis of current transportation planning practices in Texas with a focus on spatial data integration and exchange issues, meetings with transportation planning and data stakeholders, the development of a map of data sources, the development of a preliminary logical data model of spatial data entities, and a compilation of metadata documents for a sample of data sources. Developing the catalog of categories and subcategories for transportation planning spatial data was an iterative process that involved several rounds of data entity categorization; analysis of the resulting structure for inconsistencies, gaps, and redundancies; and subsequent changes to the data entity categorization scheme. In the end, the three-level grouping structure resulted in 7 categories, 63 subcategories, and 589 spatial data entities. The research also resulted in a prototype Web-based map and metadata viewer called Transportation Planning GIS (TPGIS) Data Viewer.
“Suitability of Different LIDAR Data Sets for 3D Mapping of the Road Environment”
Citation at [http://www.ingentaconnect.com/content/schweiz/pfg/2009/00002009/00000002/art00001](http://www.ingentaconnect.com/content/schweiz/pfg/2009/00002009/00000002/art00001)

Abstract: This paper presents a comparative study of LIDAR data sets and their suitability for 3D road environment mapping. For this purpose three data sets from different acquisition platforms are studied with consideration being given to not only the vectorization of elements on the road surface but also the detection of road furniture objects. While test digitizations are carried out manually, the potential of the data for automatic approaches is discussed using the methods found in recent literature as a basis. The focus of the study is to point out the strengths and weaknesses of the data sets for road mapping tasks. The results show that the decision for various data acquisition platforms is highly dependent on the final purpose for which the data is collected.

“Geometrical Aspects of Airborne Laser Scanning and Terrestrial Laser Scanning”

Abstract: This paper reviews the current state of laser scanning from airborne and terrestrial platforms for geometric reconstruction of object shape and size. The current performance figures of sensor systems are presented in an overview. Next, their calibration and the orientation of the acquired point clouds is discussed. For airborne deployment this is usually one step, whereas in the terrestrial case laboratory calibration and registration of point clouds are (still) two distinct, independent steps. As laser scanning is an active measurement technology, the interaction of the emitted energy with the object surface has influences on the range measurement. This has to be considered in order to explain geometric phenomena in the data. While the problems, e.g. multiple scattering, are understood well, there is currently a lack of remedies. Then, in analogy to the processing chain, segmentation approaches for laser scanning data are reviewed. Segmentation is a task relevant for almost all applications. Likewise, DTM (digital terrain model) reconstruction is relevant for many applications of airborne laser scanning, and is therefore discussed, too. This paper reviews the main processing steps necessary for many applications of laser scanning.

Error and Accuracy


Abstract: Cultural heritage recording and engineering surveying are prime applications for terrestrial laser scanners—TLSs—because of the high spatial resolution, high accuracy, and fast data capture rates this technology offers. To date, insufficient attention has been given to the many error sources contributing to the uncertainty of scanner datasets. A full error budget for directly georeferenced terrestrial laser scanner networks that considers both relevant error sources fundamental to surveying and those unique to sampled laser scanner systems is derived. In the case of the latter, new probabilistic models are proposed for angular positional uncertainty due to laser beamwidth and centroid-based target pointing. Analysis of a cultural heritage-recording project in Ayutthaya, Thailand, highlights the disparity between “expected” precision and the more realistic precision indicated by the error budget and demonstrates that the beamwidth error can be a significant factor. The causes and effects of several systematic errors inherent to TLS datasets are also discussed.

“Airborne LiDAR: In-Flight Accuracy Estimation”

This article describes how a “flexible quality-monitoring tool that assesses data quality in-flight avoids costly problems that are currently detected only in post-processing.”

Integration of LiDAR and Photogrammetry

“Integration of Photogrammetry and Terrestrial LiDAR”

*From the site:* “Much of CAST’s research efforts involve new approaches to spatial data and the development of new methodologies for analysis of these data. The integration of photogrammetrically derived spatial data
and terrestrial LiDAR (often referred to as HDS) is a perfect example of this effort. The methods of integration developed have led to a comprehensive site model for Tiwanaku, Bolivia. This site model includes data from not only photogrammetric processing and LiDAR, but also data from a geophysical survey, a total station survey, and historic topographic data from 1911. Together, this data tells a story that no one data set can tell. One of the biggest benefits experienced from this model has been the increased ability to interpret geophysical data (data collected by ground penetrating archaeological instruments that detect objects within 3 meters of the surface).

“Integration of Dynamic LiDAR and Image Sensor Data for Route Corridor Mapping”
Abstract: Building and maintaining modern transportation infrastructure demands considerable expenditure for any nation. These terrestrial route corridor zones include road, rail and to a lesser extent waterways. Road networks range from large highways and motorways covering hundreds of kilometers down to smaller street networks that may only be few hundred meters in length. These route networks attract their own unique set of spatial information requirements in terms of overall management. These include transportation planning, engineering and operation. High quality, timely spatial information is required of the entire route corridor, which now extends past the narrow confines of the road surface and includes the area adjacent to the road edge as well as areas above and below the road surface. Comprehensive 3D spatial information is required not only of the network itself but also of objects occurring along these route corridors. This information can be used to address the day to day engineering problems as well as more strategic issues such as road safety, congestion management and noise modeling. LiDAR systems are widely available and now used to record data from both aerial and terrestrial survey platforms. LiDAR outputs X,Y,Z points, enabling reliable 3-D measurements as well as 2.5-D geometric surfaces to be produced. High quality imagery is also collected from similar airborne and terrestrial mobile mapping platforms. This paper examines the integration of road survey imagery and airborne LiDAR data-streams within a GIS in order to satisfy these spatial information requirements.

Resources
Organizations in the United States and worldwide are working to advance LiDAR technology and its applications. Some also convene conferences and publish journals on this topic.

American Society for Photogrammetry and Remote Sensing
http://www.asprs.org
ASPRS addresses LiDAR through its LiDAR Committee (http://www.asprs.org/society/committees/lidar/). ASPRS also publishes the journal Photogrammetric Engineering and Remote Sensing (http://www.asprs.org/publications/pers/).

International Society for Photogrammetry and Remote Sensing
http://www.isprs.org/
ISPRS addresses LiDAR through several of its committees, or “Technical Commissions”:

- Image Data Acquisition—Sensors and Platforms
  http://www.isprs.org/technical_commissions/tc_1.aspx

- Photogrammetric Computer Vision and Image Analysis

- Close-Range Sensing: Analysis and Applications
  http://www.isprs.org/technical_commissions/tc_5.aspx

The site lists conferences and symposia worldwide related to remote sensing, some of which are related to LiDAR. ISPRS also publishes the ISPRS Journal of Photogrammetry and Remote Sensing (http://www.itc.nl/isprsjournal/).
U.S. DOT’s Research and Innovative Technology Administration manages seven remote sensing consortia in the areas of infrastructure, freight and environment and planning. These are listed below, including Web sites where available. The Web sites of two of these consortia, the University of North Carolina Charlotte and University of California, Santa Barbara, discuss the use of LiDAR.

**Infrastructure—Pavements**  
Western Research Institute

**Infrastructure—Bridges**  
University of North Carolina Charlotte  
[http://ncrst.uncc.edu/](http://ncrst.uncc.edu/)

**Infrastructure—Rural Roads**  
South Dakota State University

**Freight—Border Crossings**  
Ohio State University

**Freight—Congestion Pricing**  
Rensselaer Polytechnic Institute  

**Freight—Metropolitan Ports**  
University of California, Santa Barbara  
[http://www.ncgia.ucsb.edu/ncrst/](http://www.ncgia.ucsb.edu/ncrst/)

**Environment and Planning**  
Mississippi State University  
[http://www.ncrste.msstate.edu/](http://www.ncrste.msstate.edu/)

**International LiDAR Mapping Forum**  
The 10th International LiDAR Mapping Forum will be held in Denver on March 3–5, 2010. The Web site for this conference and exhibition provides several industry and research links in the “LiDAR Resources” menu:

- LiDAR System Manufacturers  
  [http://www.lidarmap.org/resources/manufacturers.aspx](http://www.lidarmap.org/resources/manufacturers.aspx)
- LiDAR System Operators  
  [http://www.lidarmap.org/resources/operators.aspx](http://www.lidarmap.org/resources/operators.aspx)
- LiDAR Support Services  
  [http://www.lidarmap.org/resources/support.aspx](http://www.lidarmap.org/resources/support.aspx)
- Government LiDAR Sources  
  [http://www.lidarmap.org/resources/govsources.aspx](http://www.lidarmap.org/resources/govsources.aspx)
- Technical Resources  
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