LIDAR: Lighting the Way
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Background

Geographic information system (GIS) operations currently use many 'geo-technologies'. These geo-technologies include; surveying, photogrammetry, global positioning systems (GPS), scanning, digitizing and remotely sensed imagery, amongst others. One of the more recent technologies being applied in GIS applications is Light Detection and Ranging (LIDAR). There are both advantages and disadvantages to using LIDAR.

Generally many people think of LIDAR as an airborne system that includes precise inertial navigation (INS) tied to GPS. However other applications using LIDAR technology, such as atmospheric studies, may not be aerial based. High and low oblique angle LIDAR applications are also possible with LIDAR due to enhanced data processing and determination of angles and elevations of the instrument position. There are many advantages when using LIDAR. These include high levels of accuracy, ability to cover large areas quickly, quick turnaround and application of data as well as reasonable cost – considering the resources and time it would take to gather information of similar accuracy using conventional geo-technologies. LIDAR is also portable and can be moved easily.

Some of the disadvantages of LIDAR include the inability to penetrate heavily canopied forests without breaks, thus preventing creation of accurate DEM. In this case a DEM is calculated through mathematical modelling and filtering of the data set. The inability to penetrate buildings precludes modelling for internal architecture. LIDAR is GPS based and GPS has its own error budgets that require consideration – LIDAR operators require a sound understanding of LIDAR, GPS and INS systems, not to mention knowledge of the environments they are applying LIDAR to. There are no published policies or international protocols for LIDAR calibration and operation.

History and Operation

Developed in the 1960's, LIDAR itself is not new. The more recent development of accurate inertial navigation systems and global positioning systems have allowed for the deployment of current LIDAR systems that are capable of high precision and accuracy. Inertial navigation controls aircraft pitch, roll and yaw while GPS is used for flight path and altitude navigation and control. In the case of building a DEM, GPS provides the means to fly flight flights which edge match without large amounts of overlap – increasing quality while maintaining cost efficiency.

Earlier laser based instruments consisted of single laser pulses. Current LIDAR technology involves the rapid scanning of 10-15,000 pulses per second in a pattern perpendicular to airplane flight path. These pulses are emitted from the aircraft toward the earth's surface and reflect from the earth's surface and other objects on the surface back to the aircraft. Similar to GPS the travel time of the pulses multiplied by the speed of light (299,792,458 m/s) determines distance

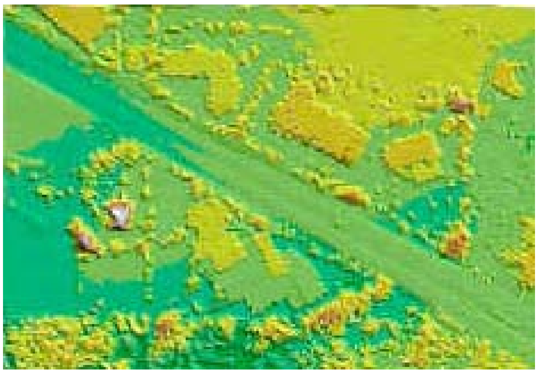

Fig: 1 Initial LIDAR point samples.

or – range. The rate of pulse emission, speed of the aircraft and altitude all play an important role in LIDAR mapping. Their roles can be thought of similar to conventional aerial photography where scale can be determined based upon aircraft altitude and camera focal length. However, in the case of LIDAR, emission angle must be determined since the scanner emits laser pulses and acquires them from multiple angles from a nadir (point perpendicular to the emitter toward the earths surface). LIDAR has been used in the study of atmospherics, flood plains, forest canopy density, agriculture and geology. By far, most LIDAR applications are for construction of (DEM). When building a DEM a series of 'raw' data points are generated for a landscape (Fig.1).

The LIDAR instrument is calibrated prior to beginning operation through the application and alignment with pre-determined ground control points. INS is also calibrated at this time. These calibrations and the initial raw data are compared and accuracy's of 50 cm. or less are common. It should be remembered that all landscape objects are visible at this stage. These objects can be 'filtered' from the initial images thereby allowing for the construction of a DEM (Fig.2). Further interpolation of the DEM dependent upon either captured LIDAR data points or ground collected elevation points may be included in the data set (Fig.3).

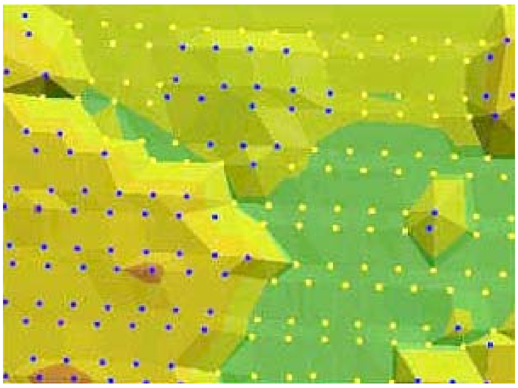

Fig. 2. DEM from LIDAR point data

The filtered data containing 'objects' is kept and may be analyzed. For example, when investigating forest cover types, constructing 3-D visualizations or delineating routes, line-work or other physical attributes. Currently a significant number of researchers internationally are studying natural environments and landscapes with a view to developing algorithms derived from LIDAR data that recognize common landscape attributes.

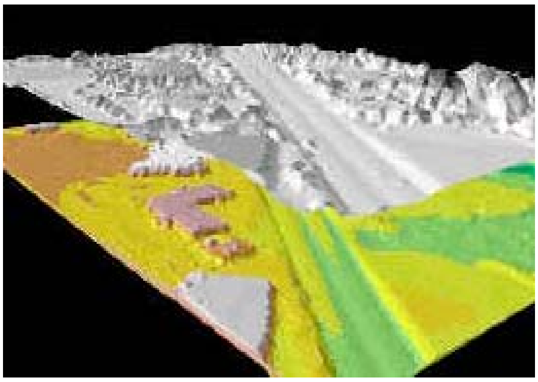

Fig. 3 Interpolated DEM - contours

The portability and rapid turn around of LIDAR information has led to the study of ice sheets in Canada, aerosols in the City of Leipzig, Germany and earthquake prone areas in the Seattle, Washington area. In emergency or natural disasters where conditions and change rapidly, LIDAR can be used effectively for the purposes of monitoring change. Since the data can be acquired locally and processed locally quicker management decisions can be made and observation of changing conditions more closely investigated. In the case of natural disasters LIDAR has other benefits due to being an aerial application, therefore reducing need and possible injury to ground based monitoring. Similarly, environments where aerosols or other dangerous airborne pollutants are present can be monitored from a distance.

Ranging and Analysis

LIDAR errors can and do occur for a number of reasons. The field of (FOV) of a LIDAR beam can be varied. Generally a FOV from ranging from 15° to 50° is used. The wider the FOV the less accurate will be the results due to lesser numbers of light pulses reflecting upon the earths surface. Higher numbers of pulses per unit area may be achieved by a number of methods including:

- Slower aircraft speed
- Lower flying altitude
- Reduced field of view (FOV)
- Increased pulse emission

A change in altitude, for example by flying higher will result in a decrease of resolution as propagation times tend to merge and subsequently 'average' together. Flying closer to ground level will result in stronger signal returns and more of them over a smaller area. This will result in improved resolution due to increasing numbers of points being sampled per unit area. Further, those objects closer to the LIDAR instrument return pulsed light sooner than those farther in distance due less atmospheric scattering.

Assume a forest canopy, and for the moment consider the forest canopy has two height classes. One height class has trees that are at 20 meters high and the other where trees are at 35 meters in height. Light pulses will strike the upper crowns of the forest canopy (if generated from above) prior to striking those of the lower height class. Further, the light pulses will strike the ground itself lastly. Those pulses striking the upper will be returned to the instrument first and those striking the ground will return to the instrument last. This is a very simple example, however it does raise some interesting questions, particularly if one is interested in investigating crown size – which might be useful for determining carbon storage and turn over rates within a forest.

Most tree canopies, if not all, are not symmetric they tend to be irregular and vary with height and density. How would you determine from an irregular collection of objects (trees), their heights, from a widely spaced collection of returned pulsed points? Similarly, a series of buildings closely spaced but of irregular shape and height will return a series of points to the instrument. How can we in such a case determine which pulses belong to which buildings thereby delineating the building – accurately in both shape and height?

To determine the shapes of objects and their corresponding heights the points returned to the emitter are collected and filtered. This can be done a number of ways including:

- Density of points with similar range – return times
- Density of points using neighbourhood / proximity analysis
- Correlation to other information including aerial photographs
- Spectral analysis in the case of multi-spectral emitters
- Object analysis – linking physiology / biology
- Structural analysis – building design / surfaces

In each of these cases we are interested in the analysis of the returned light pulses (Fig. 2). There is considerable current research into the development of algorithms that can be used to correlate landscape objects and environments to LIDAR returned point distribution both spatially and temporally. These investigations often involve similar methods and techniques used in remote sensing analysis.

Vertical LIDAR

Vertical LIDAR refers to the placement of a LIDAR instrument perpendicular to the earth surface (side-view). Similar to aerial LIDAR, vertical applications of LIDAR are designed to acquire a representation of the sides of buildings, trees, bridges and other landscape objects. Perhaps a model is needed for an oil refinery or historical building, in which case vertical LIDAR can be applied to quickly build a model suitable for integration into a GIS or other visualization software.

In the study of biological environments, vertical LIDAR holds great promise for the determination of ecological bio-diversity when applied from the side since patterns and structure of biological entities can and do vary beneath canopies trees. One investigation using conventional light laser studied side-views of forest canopies using laser, GPS and image analysis (Fig. 4). In this image the viewpoint is from the top-down. Those objects closer to the laser are at the top and the point distances have been analysed from the side using GIS neighbourhood analysis.

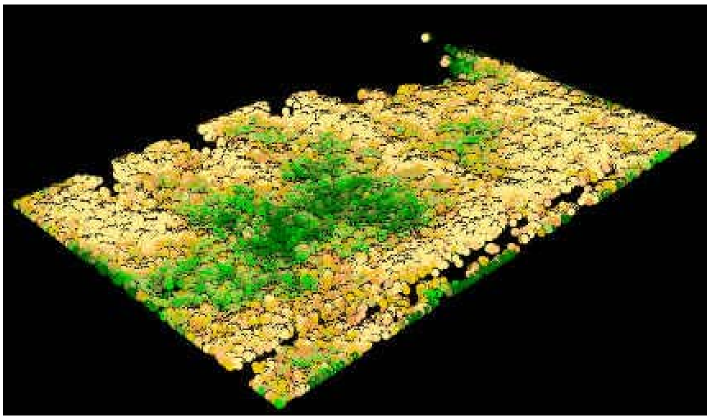

Fig. 4 Side-view of forest – 12 classes.

LIDAR point side-view data tables can be collected for other objects besides forests. (Fig. 4) is classified into 12 classes, however, it is almost impossible to determine actual tree shapes. Other researchers are working on this problem and developing techniques for the analysis of both raster and vector models of the point distributions. It should come as no surprise that with greater numbers of emitted light pulsed points returned, resolution improves. Finally, after analysis of the point distributions, thematic layers suitable for GIS analysis can be developed (Fig. 5).

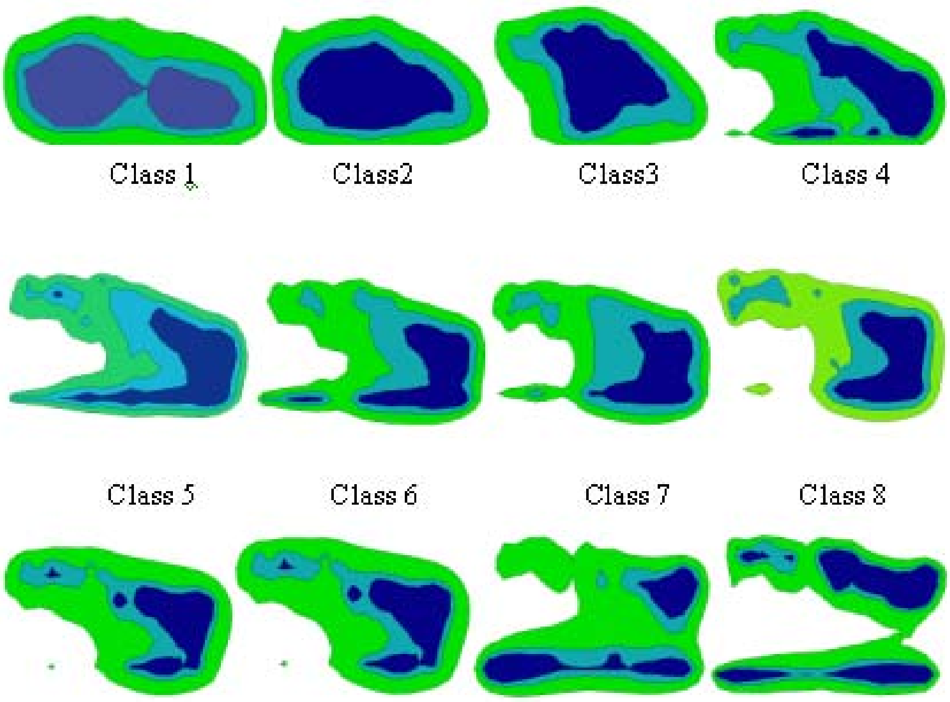

Fig 5. GIS thematic vertical layers by class

Connection to GIS

LIDAR is well suited for GIS applications due to the fact the data is processed rapidly, is geo-referenced and can be readily imported into a GIS. Imported data is in vector format consisting of spatially distributed points. From this topology many GIS functions may be performed including aggregation, neighbourhood / proximity analysis, spatial statistics and contour modelling to name a few. Most LIDAR information is used for the study and building of digital elevation models. In the case of atmospheric applications, multi-spectral LIDAR allows for quick monitoring of aerosols, where varying light pulses of different wavelength result in thematic layers being created for individual type of airborne particles. GIS image analysis software is being increasingly used to differentiate between light points of differing time returns and or differing spectral colour.

The data captured with LIDAR can be readily integrated with other thematic content if all information is geo-referenced. Issues related to scale and resolution require consideration, since LIDAR information tends to be quite accurate with sub-meter resolutions while other data sets may be of a coarser resolution. The GIS professional is ideal to work with LIDAR datasets since GIS people tend to 'think thematically'. While many LIDAR applications are being used for constructing 3-D models, there is currently a high need for individuals who are capable of deriving thematic content from these models. Evaluation and analysis of 3-D models for spatial and temporal changes will become increasingly more important and useful. GIS professionals are also well situated to integrate additional data sources to LIDAR data from alternate technologies in both raster and vector formats with knowledge. This will open the door to fully capitalize on LIDAR applications while providing new application opportunities.

LIDAR provides great opportunities for the GIS professional in both vertical and horizontal environments. Future applications are likely to be coupled to artificial intelligence and real-time coupling to other instrumentation. One of the primary benefits of LIDAR is the quick construction of 3-D and 4-D models.

Additional Links / Information

Internet Links	Publishing / Presentations
LIDAR - introduction **Coherent LIDAR – Wind mapping** **Air Monitoring – Traffic pollution** **Filtering – Digital elevation models** **Bathymetry – Water brightness** **Linking – Forest stands to hydrology** **Entertainment – Movies using LIDAR** **EARLINET – European Network on LIDAR**	**Spencer B. Gross – LIDAR** **Flood Plain Mapping – U.S. Army** **Forest Inventory – LIDAR** **Buildings – Historical** **Disaster – Earthquakes** ***PowerPoint required**

References

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Clarke, K., Parks, B. and M. Crane. 2000. Integrating geographic information systems (GIS) and environmental models. In: Selected Papers from the 4th International Conference (GIS/EM4). *Journal of Environmental Management*. Vol. 59. pp. 229-233.

CYRA Technologies Inc. Oakland, California. (On the Internet: www.cyra.com)

NASA, Earth Observatory, Vegetation Canopy LIDAR.
(On the Internet:http://earthobservatory.nasa.gov/Library/VCL/VCL_2.html)

Spencer B. Gross, LIDAR Technologies. Portland, Oregon. (http://www.sbgmaps.com/)

The German LIDAR Network.
(On the Internet: http://www.iap-kborn.de/optik/aer_trop/AFS/AFS_e.htm)

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