FUTURE FORESTS RESEARCH

HARVESTING TECHNICAL NOTE

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The Potential of LiDAR in New Zealand Forest Engineering

Summary

Light Detection and Ranging (LiDAR) has the ability to collect highly accurate elevation measurements of objects above the ground as well as surface topography. For topographical mapping, the ability of LiDAR to penetrate the forest canopy measuring the true elevation of the ground means the accuracy and detail of the Digital Elevation Model (DEM) created can far exceed what can be produced using aerial photography. The quality of the LiDAR derived DEM means that it has huge potential to change the way we plan and execute many different types of forest engineering projects. This is particularly true when harvesting forest planted on steep country. Although the technology has been around for over 50 years, it has only recently been applied at an operational level in New Zealand forestry. Although the price has reduced over the past few years it is still expensive to acquire LiDAR data. However, there is a growing weight of evidence that suggests that for forest engineering applications LiDAR may be cost effective, particularly when other potential uses such as forest inventory and environment monitoring are factored in.

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Introduction

Light Detection and Ranging, or LiDAR, technology has existed for many years (since the development of lasers in the 1960's), but its potential uses in forestry have only been explored in the last 15 years. LiDAR is similar in concept to Radar (radio detection and ranging) but with laser light pulses replacing radio waves. LiDAR uses either ultraviolet, visible or near infrared light to image objects. The ray of light in the form of a laser is directed at the object of interest, and is reflected back to a sensor (Figure 1).

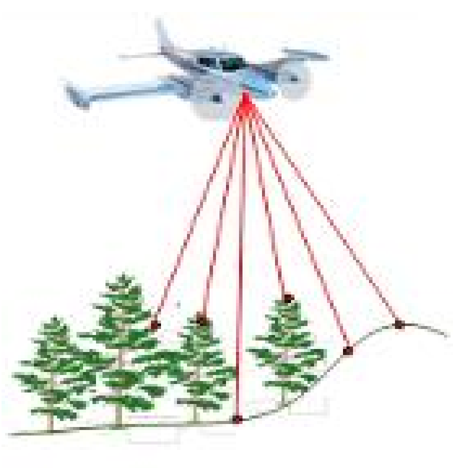

Figure 1. Airborne LiDAR

As the speed of light is constant, collecting the light's return time alongside an accurate location of the LiDAR unit position allows the three-dimensional location of any object to be determined.

LiDAR is an active remote sensing technology, and when a LiDAR sensor with integrated Global Positioning System (GPS) and Inertial Measurement Unit (IMU) technology is placed in a plane (airborne LiDAR) it can be used to collect highly accurate elevation measurements of objects above the ground as well as surface topography (White *et al.* 2010). Terrestrial LiDAR (ground-based) refers to measurements that are taken from a tripod-based sensor. LiDAR technology has been applied to many different fields such as atmospheric research, hydrology, archaeology, mining, construction and traffic enforcement. The focus of this paper is on the application of airborne LiDAR in forestry, with a particular emphasis on forest engineering.

Common LiDAR terms

Like all new technologies there is always an accumulating list of jargon and confusing terms. The following is a range of commonly used terms used in the application of LiDAR.

Bare earth: This describes the earth surface excluding any vegetation, natural objects such as rocks and man-made structures such as buildings.

Digital Elevation Model (DEM): An acronym used as a generic term for digital topographic data.

Digital Surface Model (DSM): Elevation data set containing accurate x, y, and z coordinates of all the LIDAR systems return. A DSM contains all the

topographic, plan metric and vegetative information of the area.

Ground returns: The LiDAR returns that hit the ground. These are important for creating a DEM.

LIDAR Intensity: The strength of the light pulse being observed. Different objects will reflect laser light back at different intensities.

LIDAR Pulse Rate: The number of light pulses sent out of the LiDAR unit per second.

Pulses per m^2: The number of light pulses per m^2 that are sent from the LiDAR unit.

Returns per m^2: The number of returns per m^2 is the number of light returns that the LiDAR receiver receives back. Many of the modern LiDAR units can receive multiple returns, as the same light beam reflects back off different objects in the forest canopy.

LiDAR Classification: As part of LiDAR processing, points are classified into categories based on the object that the point represents, for example ground, building, vegetation etc.

Potential forest engineering applications

To date the most common commercial application of LIDAR technology is topographic mapping. This is the process of turning the cloud of three dimensional co-ordinates collected (Figure 2) into a digital elevation model (DEM).

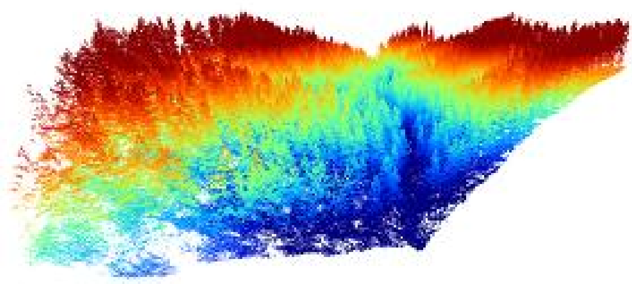

Figure 2. The full LiDAR data cloud.

The laser light of most modern LiDAR units has the ability to penetrate through the tree canopy. The detail of these DEMs is often impressive (see Figure 5), revealing topographical features that cannot be seen in either aerial photos or on the ground, such as landing locations, difficult or historic stream crossings, unstable soils, difficult side-slopes, useful benches and old roads (Krogstad and Schiess 2004). LiDAR also has the advantage over other methods of mapping topography, in that processing of the data can be largely automated.

LiDAR also provides very detailed and very accurate DEMs. The NSW Department of Primary Industries carried out a study comparing field survey results with the data produced from the LIDAR image. It was found that the accuracy of the LiDAR was within 2 metre variance in the horizontal plane and 60 cm to 70 cm in the vertical plane (Turner 2007). Other researchers have found a high correlation between LiDAR-derived topography and true topography based on terrestrial mapping (Reutebuch *et al*., 2003). Work carried out by Krogstad and Schiess (2004) showed hill side profiles generated using LiDAR were almost identical to those measured using field-based techniques, whereas the profiles generated from the traditional map series used in that region missed a bench that was clearly shown in the LiDAR-derived profiles. Hugelschaffer (2004) found that the overall accuracy of the X,Y,Z measurements of LiDAR was within 10-15 cm.

The following example (Figure 3) shows the difference in contours produced using LiDAR (collected at 12 pulses per m^2) and 20 metre contours which are available from Land Information New Zealand (LINZ).

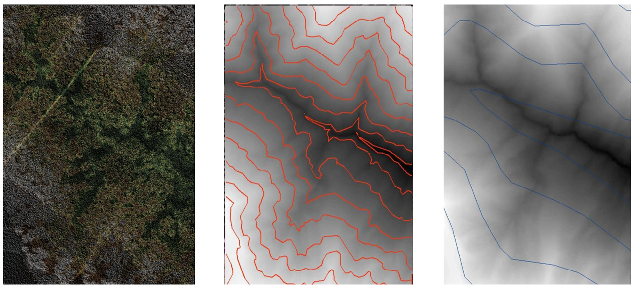

Figure 3. From left to right: LiDAR point cloud, 10 m contours produced from LiDAR and 20 m contours from the Topo 250 map series.

It should be noted that most forest companies will most likely have more accurate contour maps than those available as part of the Topo 250 series.

The use of high quality DEMs, as in Figure 4, in harvest planning can have a number of benefits such as an improved identification of the landing locations, and difficult areas and exclusions zones such as streams and wetlands.

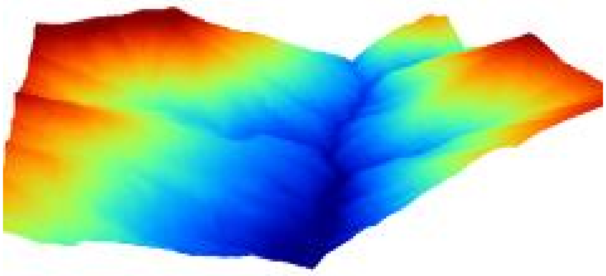

Figure 4. The digital elevation model derived from LiDAR

The accurate calculation of the slope class would allow for better determination of whether ground based or cable harvesting is appropriate. This is one area in harvest planning where significant benefits for cost saving and health and safety management could be made in New Zealand.

The use of cable logging planning software tools such as CYANZ and LoggerPC is limited in New Zealand. One reason for this may be the inaccuracy of the topographical information; these inaccuracies lead to decisions being made that can not be implemented in the field, due to differences in the modelled topography as against the true topography. The availability of highly accurate LiDAR-derived DEMs and elimination of the disparity between predicted and actual topography may lead to the wider scale use of software tools such as CYANZ and LoggerPC.

There is no reason why a LiDAR-derived DEM could not be deployed onto on-board computers on harvesting equipment. When combined with GPS technology it could provide operators with real-time information about the ground surface that they are working on, helping with optimal load accumulation and skid trail selection etc.

The potential of LiDAR in roading planning and design is significant. Both case studies highlighted later in this report (see Case Study) have utilised LiDAR in road construction. A study carried out by White *et al.* (2010) showed the success of using LiDAR for mapping forest roads in steep forested terrain beneath heavy vegetation. Another paper by Aruga *et al.* (2006) investigated how different resolution grids from a 4 pulses/m^2 LiDAR data source affect its use in road planning. The research showed that a 4.5 m grid DEM was acceptable for forest road alignment optimisation, total costs and soil sediment calculations. As the size of DEM increases to be greater than 10 m, the alignment of the measurement made by total station of road cross sections decreased. The ability to describe accurately the macro and micro topography means that cut and fill calculations can be extremely accurate, enabling much more accurate costing of road construction.

Forestry case studies

City Forests Limited

Guy Bonner, Harvest Planner at City Forests Ltd, was contacted to plan the harvesting of two Dunedin City Council-owned forest blocks which were outside City Forest’s normal mapping and flying areas. LiDAR data were available for this area from the City Council. The data could be imported easily into RoadEng computer road design software and used to prepare the roading and harvesting plan for the blocks. Using the LiDAR-derived DEM it was even possible to spot an existing stream crossing that was not identified during the ground survey due to the presence of heavy undergrowth.

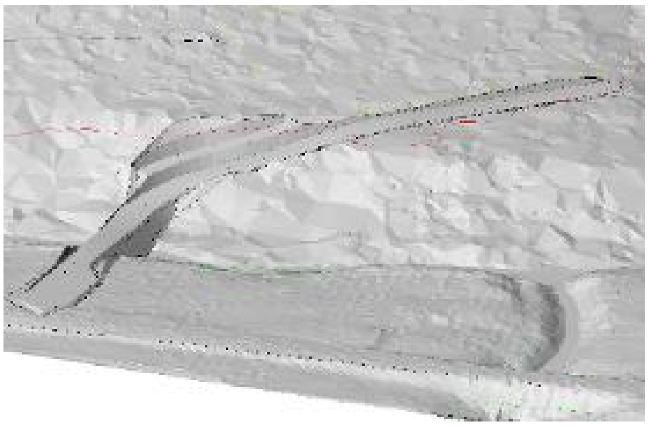

Figure 5. Road construction detail overlaid over a LiDAR derived DEM (Provided by City Forests Ltd)

The LiDAR data set was used as part of the resource consent hearing process to analyse the shading effect on local residents before and after harvesting

of one of the blocks. The DEM easily and correctly identified cable profiles with a lack of deflection. Overall the use of LiDAR was extremely impressive and the potential particularly for analysing road and track construction options was well demonstrated (Guy Bonner, pers. com.).

PF Olsen Ltd

Jacob Saathof, Harvest Manager with P.F. Olsen Limited carried out a small LiDAR project in Rotoiti Forest using LiDAR sourced from the Rotorua District Council to prove the practicality of LiDAR and associated technologies in forestry earthwork operations. The LiDAR data were of average quality, but the accuracy of the road layout was 1 metre in the horizontal plane and 0.5 metres in the vertical plane. As a result of this and other trials, P.F. Olsen limited have commissioned the flying of three steep country forests in the Eastern Bay of Plenty for LiDAR data collection.

Australian applications

In New Zealand the use of LiDAR in forestry has so far been limited. In Australia this is not the case with many of the large forestry organisations such as Forestry Tasmania, ForestrySA, and Forests NSW all undertaking large LiDAR projects. As widely reported, Forestry Tasmania have flown over much of their estate and found the tallest eucalyptus tree in Australia using LiDAR.

Pitfalls of LiDAR for forest engineering

The following section lists some of the potential pitfalls of using LiDAR and LiDAR-derived DEMs for forest engineering applications:

- The quality of the DEM depends on the number of ground returns achieved. A low number of ground returns can produce a low quality DEM particularly when the vegetation is dense. Thick low growing vegetation such as blackberry can produce false ground returns.

- The large amount of topographical detail contained in data surfaces and profiles derived from LiDAR can cause processing problems with current forest engineering software (Dr Kevin Boston, pers. com.).

- Using LiDAR-derived topographical maps with the high level of topographic detail can lead to a false confidence in the data (Krogstad and Schiess 2004).

- To create the DEM, the LiDAR point cloud data needs to be filtered so only the bare earth points are used. This filtering process can lead to two kinds of mapping errors. Not filtering enough of the tree-intercepted LiDAR can lead to incorrect topography being created. Being overly aggressive with the vegetation filter can lead to the elimination of real topography such as large rock outcrops along ridgelines. Often this filter or classification process is carried out by the data provider, so it is important that these data are checked (Krogstad and Schiess 2004).

Other uses in forestry

LiDAR has many potential uses in forestry other than forest engineering. The literature is full of research papers on using LiDAR for forest mensuration (to predict canopy height, stand basal area and standing volume). The majority of the LiDAR forest inventory applications use a double sampling approach to create relationships between LiDAR metrics and ground measurements. The quality of the relationships can allow detailed maps/surfaces of canopy height, basal area and volume to be created across an entire forest or estate. LiDAR can also be used to count and locate trees in a stand. The New Zealand national land use carbon accounting system (LUCAS) uses LiDAR to improve the precision of New Zealand national carbon estimates for the whole of the New Zealand planted forest estate (Stephens *et al.* 2007).

The topographical detail that exists in LiDAR data sets means that the location of drainage features in the landscape can be determined to a level of accuracy that could not be achieved with most topographical map series. Forestry Tasmania found that rivers that were mapped running one direction in historical contour maps in fact ran in the opposite direction in the LiDAR DEMs. LiDAR can also be used to map and identify potential landslides. In a study carried out in the Seattle area in Washington State, four times more landslides were mapped than by using aerial photographs (Schulz 2006).

LiDAR's ability to collect multiple returns as the laser light travels through the forest canopy means that there are many potential applications for forest health monitoring. In Norway LiDAR has been investigated as a means to developing a nationwide forest health monitoring system (Solberg *et al.* 2004). The ability of LiDAR to penetrate the canopy of the planted trees and strike the undergrowth means that it could be used to determine biodiversity. In other countries such as Australia and the USA, LiDAR has also been used to determine fuel loading in forests (Turner 2007).

Obtaining and analysing LiDAR

Obtaining LiDAR data is expensive; the price depends on the size of the area being surveyed. The latest published pricing information would indicate that to fly your own forest for LiDAR will cost anywhere from $100 per hectare for a small project of 50 hectares to as little as one to two dollars if you are flying large areas of 10,000 plus hectares (Adams *et al.* 2011). The cost of flying LiDAR is dependent on numerous factors. Therefore the best way to obtain an accurate costing is to contact a LiDAR provider directly. Currently NZ Aerial Mapping Limited (NZAM) is the only New Zealand-based company flying LiDAR. It is possible to obtain LiDAR from organisations that have previously collected LiDAR for other uses. In the past a number of New Zealand local authorities have collected LiDAR data sets, particularly around urban areas. Care must be taken when sourcing data in this fashion as it may not have been flown to the specifications that are required for your application.

It is important to remember when obtaining LiDAR data sets that even a moderate sized forest takes up many gigabytes of disk size. "Converting whole LiDAR datasets into raw point coordinates is a fast track to "Out of Memory" errors and overnight runs" (Adams *et al.* 2011).

There are numerous engineering and geographical analysis software products that support LiDAR data. A number of ArcGIS extensions can display and view LiDAR data (ESRI 2010). Most of the commercial LiDAR tools can be quite expensive. One of the best free forestry-related LiDAR analysis software products is Fusion[1] developed by the US Forest Service. Fusion has Windows™ interface for carrying out some basic LiDAR analysis but also a long list of DOS™ command line tools for carrying out a range of LiDAR analyses. Another free option is LAStools[2] which has a number of command line tools for creating DEMS, and clip and merge data sets. To get started a good free LiDAR viewer is FugroViewer[3] .

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[2] https://www.cs.unc.edu/~isenburg/lastools
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