AIRBORNE LASER SCANNING: DEVELOPMENTS IN INTENSITY AND BEAM DIVERGENCE

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Abstract

Airborne Laser Scanning (ALS) is becoming widely accepted as a broad-acre terrain modeling technique. As a mapping tool, it can define the terrain with a dense array of points, at a rapid acquisition rate and to a high degree of accuracy. As a surface modeler, it can simultaneously define building outlines, vegetation canopies and vegetation extents. As these fundamental uses are now bedded into the Australasian market, attention can be turned to the wealth of other information contained within an ALS system. This paper concentrates on recent advances on two such features, viz. laser intensity and beam divergence.

An ALS system emits a discrete beam of light and records the time and intensity of the beam returned to the aircraft. The *time* taken for the beam to return allows one to calculate the *distance* to the terrain. The *intensity* of the return signal gives one an indication of the surface that reflected the beam. Work is continuing to utilise the information contained in the intensity return. An initial application is to produce a grey-scale image from the intensity returns; a product that is instantaneously useable as is it is already georeferenced and ortho-rectified. Some work is required to standardise the intensity returns to improve the images' visual appearance. Applications and examples are provided. Future applications for the intensity return could include using intensity to assist data classification, feature extraction and vegetation species identification.

A second interesting development in ALS hardware is the concept of "wide beam divergence". The laser beam is emitted from a small aperture at the aircraft, and diverges (i.e. gets wider) as it travels to the ground. Early ALS hardware was designed to keep the width of the laser beam as narrow as possible so that, when it strikes the terrain, it measures as precise a piece of ground as possible. Typical beam divergence is 2 millirads, which equates to a footprint diameter of 0.25m from a 1200m altitude. The concept of "Wide Beam Divergence" was introduced in recognition that ALS users may want to measure features other than the terrain. By introducing this option, the flight can be designed so that each laser footprint effectively joins its neighbor. Typical wide beam divergence of 8 millirads equates to a footprint diameter of 0.96m. Potential uses for this option are mainly in forested areas. For canopy definition, a wide beam will "always" return the top of every tree. For terrain mapping in very heavy timber, the laser will "always" find any available gap in a dense canopy. Another potential use is in

measuring powerlines; a wide laser beam has more chance of hitting the powerline then a narrow beam.

Recent research and examples of both intensity returns and wide beam divergence will be presented in the paper.

Background

Airborne Laser Scanning (ALS) became operational around the early to mid 1990's as a broad-acre terrain-modelling tool. It was adopted soon after in the USA, where the term LiDAR (for Light Detection and Ranging) was adopted as the term for the technology.

The concept of ALS is quite simple. A NAVSTAR Global Positioning System (GPS) receiver in the aircraft records measurements that allow the position of the aircraft to be calculated throughout its trajectory. An Inertial Measuring Unit (IMU) in the aircraft records its *orientation*. Thirdly, a laser distance measurement system emits a discrete beam of light at a wavelength of 1.047 microns and measures the time it takes for the light beam to reflect from the ground and return to the aircraft. The distance to the ground is calculated with the time taken and the known speed of light. Knowing where the aircraft is and the direction it is facing, distances to the ground can easily be computed into ground elevations (Figure 1). A summary of the position of ALS in the Australasian market can be found in Jonas [2002].

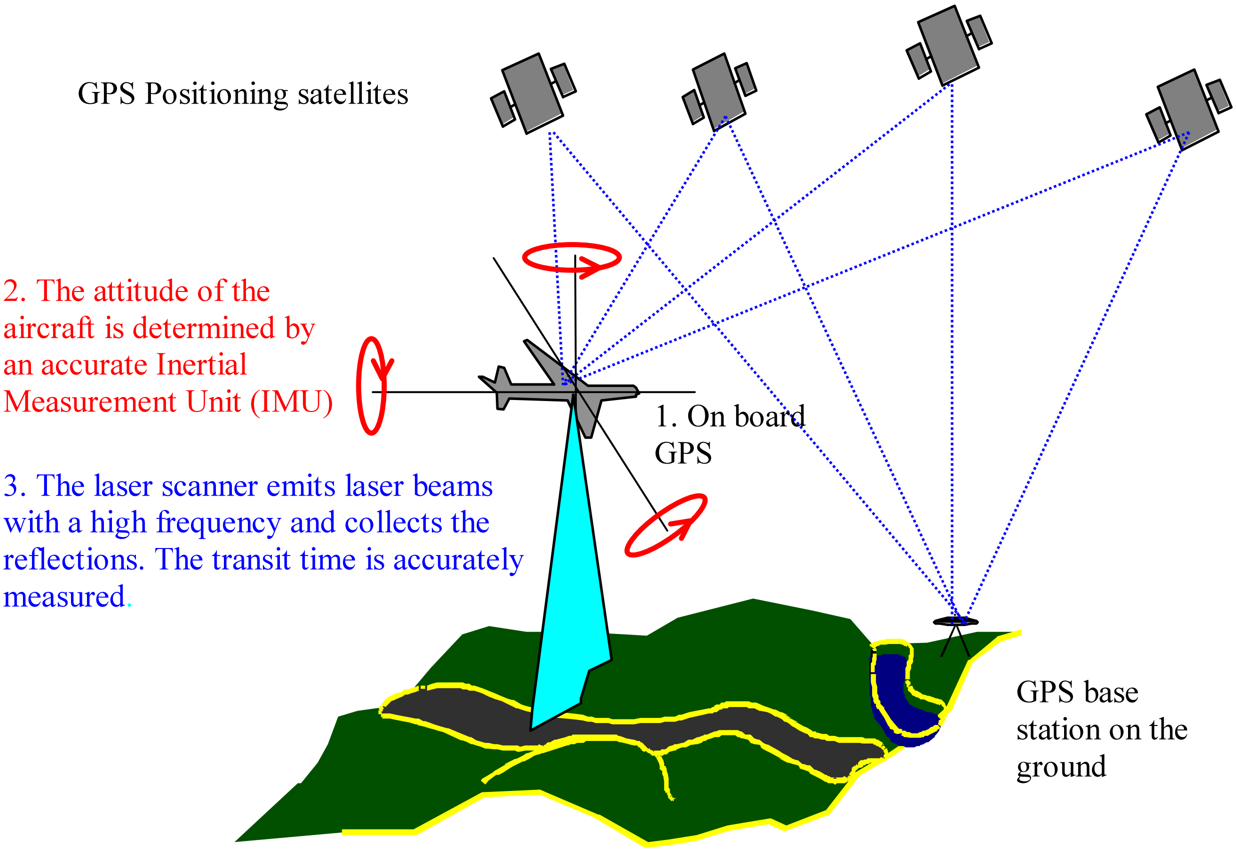

Figure1 – Schematic showing the three measuring systems in an ALS

Laser Characteristics

Early ALS trials showed that the distance-measuring laser would measure more than just the ground heights. The wavelength of light selected for the laser (1.047 microns) meant that, like a beam from a torch light, the laser would be reflected from most features above the ground. This meant that a whole new range of surfaces could now be defined from the air. Applications found to take advantage of this element of ALS include:

- Forestry – as the top of the trees can define the canopy model;
- Electricity Distribution – as the powerline conductors also reflect a sufficient amount from the laser to define the powerlines hanging in catenary; and
- Urban planning – as building rooflines can also be defined en masse.

A second characteristic of the laser is that one emitted laser beam can be reflected from a number of different surfaces. Continuing the analogy from above, if someone shone a torch light straight down from an aircraft at night, the torch beam could show the top of a tree, a lower branch, a power line hanging above the tree and, if the tree wasn't too dense, the ground beneath the tree. So too, the measuring laser would be reflected from all of these different surfaces. Early ALS hardware was configured to record the time taken for the *last* of the beam to return to the aircraft. This gave the best chance of recording the ground surface. Current hardware can record the *first return* (which will measure the tree canopy or powerline conductor) and the *last return* (generally the ground surface). Some sensors record intermediate returns as well.

Hardware Characteristics

Hardware performance has improved markedly since the mid-1990's. There are two major equipment manufacturers in the market, viz.Optech (ref: http://www.optech.on.ca) and Leica (ref:

ftp://ftp.gis.leica-geosystems.com/outgoing/docs/ada/ALS40_Product_Description.pdf). Most of the author's experiences are with the Optech range of laser scanners, but the principals apply equally to the Leica scanners.

ALS systems can now be purchased with the following characteristics:

- laser emission rates up to 50,000 points per second;
- laser recording up to 5 returns per emission;
- operating altitudes up to 3000m;
- swathe width up to 2100m in a single pass of the aircraft;
- vertical accuracy up to 0.15m rms;
- variable width of laser beam;
- signal strength of return laser recorded.

Most of the hardware advances listed above are in the "Olympic" class, viz. *Citius, altius, fortius* or, for those not familiar with the Olympic motto, "swifter, higher, stronger". The two advances that are not in this category involve the ability to vary the width of the laser beam, and the ability to record the return intensity of the laser signal.

The hardware manufacturers introduced both of these features some time back, but little use has been made of these features to date. In some regards, they were added to the system capabilities because they were reasonably easy to do at the hardware manufacture stage, in the expectation that the industry will be able to make use of them in the future.

Intensity Returns

Background

The ALS system emits a discrete beam of laser light and records the time and strength (or intensity) of the beam once it has reflected off the surface below. As Figure 2 indicates, a single beam can be reflected from a number of different surfaces, each with its own time (and so distance) and its own intensity.

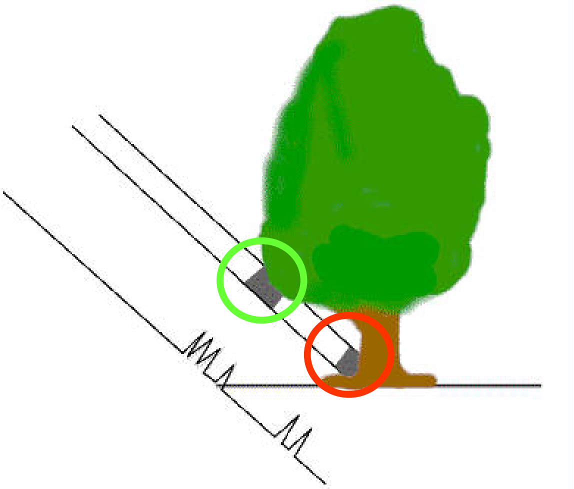

Figure 2 – The emitted laser is reflected from a number of surfaces, each returning a different amount of the emitted beam

ALS hardware typically records the time and intensity of the FIRST and the LAST surface reflecting the light.

The definition of the magnitude of the intensity measure provided by Optech for their scanner is:

> *The ALTM intensity value is a measure of the return signal strength. The data is produced by the intensity module, which measures the peak amplitude of the first and last return pulses. For the case where there is only one return pulse the data for the last return will be the same as that as for the first return, since there is only one return pulse. The intensity return values are considered relative rather than absolute measurements*

> *The intensity range is from 0 to 8160, 0 being a very weak return and 8160 being a very strong return. The return intensity is based on several factors such as; flying elevation, atmospheric conditions, directional reflectance properties and the reflectivity of the return target. For these reasons the measured return intensity may not be consistent for a given target. For instance, multiple flights over a homogeneously reflective surface could conceivably produce a wide range of intensity values. This is not to say, given the appropriate modelling constraints, a set of corrections could not be derived, although the directional reflectance may pose an interesting problem.*
>
> *The information to determine the peak amplitude of the return signal is not readily available in the current output data formats. Also note, at this time we do not guarantee the linearity of the intensity measurement.* [Conrad, 1999]

Experience

Experience with Optech ALS systems shows that there is a wide variety of factors which affect the magnitude of the recorded intensity. For a particular ALTM3025 system, the following intensity characteristics have been noted:

- intensities measured over uniform terrain typically display a traditional "bell" histogram:

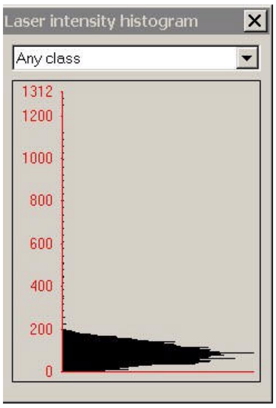

Figure 3 –Typical intensity histogram

- typical range of intensity values flown at 1100m is between 100 and 300;
- sorties flown during hazy conditions can lower the intensity range to below 100;
- although most measured intensities are below 300, most sorties include a few larger measurements up to 2000 or more. The distribution in Figure 4 is typical.

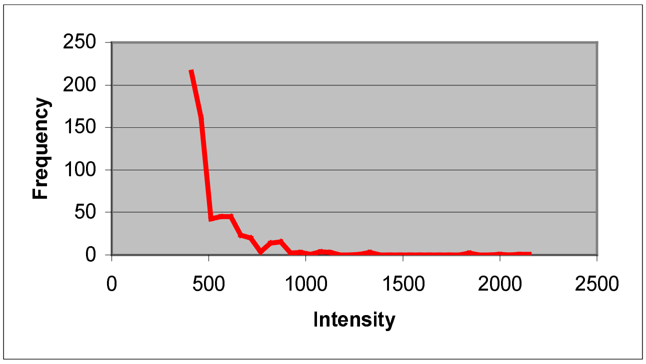

Figure 4 – Intensity histogram, showing intensities above 400

- Lowering the flying height increases the magnitude of the intensity returns;
- bitumen roads typically return an intensity below 20;
- powerlines typically return an intensity below 5.

Current Applications

One application of the intensity returns is to produce a greyscale image of the project area scanned. Because the wavelength of the laser's light source (1.047microns) is only slightly larger than light in the visible spectrum, the reflection of the laser equates reasonably well to the natural appearance of reflected visible light. Equating a greyscale colour to graduations of the laser return produces a image that closely resembles a monochrome (or "black-and-white") image of the terrain. These images are already true-to-scale as they have been compiled simply by colour coding the spatially-correct ALS data. Examples over different project areas can be seen in Figure 5 and at O'Hagan [2002].

Figure 5 – Sample greyscale intensity images: rural (below) and urban (top)

Future Developments

There are three future applications of ALS intensity measurements that are actively being pursued.

The first is in the never-ending quest to improve the accuracy of ALS data. Most ALS projects are larger than can be recorded in a single pass of the aircraft, so the aircraft moves up and down the site in a regular pattern covering the data with overlapping swathes of data (figure 6).

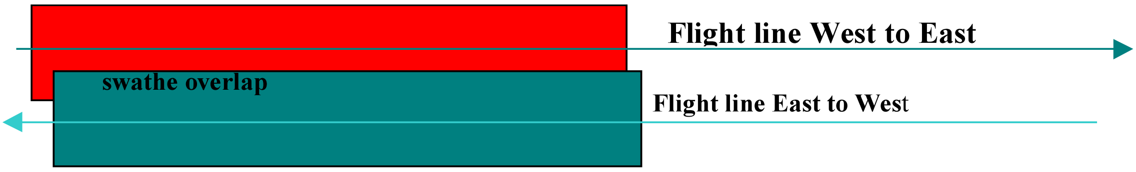

Figure 6 – Parallel swathes have an area of overlap (typically 25% of the swathe width)

The terrain between the swathes has effectively been recorded twice, once in each direction. This redundant information can be used to identify and remove any remaining errors in the measurement process, but only if the software can identify a common element that was been recorded twice Figure 7). Developments are underway to utilise terrain shape and intensity variations to identify these elements common between swathes. [Terrasolid 2002].

Figure 7 – Items appearing in the swathe overlap are measured twice

The second future development of intensity recording is to improve the data classification and/or feature extraction capabilities. Fundamental ALS data is simply a three-dimensional coordinate of the feature which reflected the laser. Software is used to subsequently classify the acquired data by deciding *what* the laser reflected from. The most common classification routine separates those laser strikes that hit the ground, from those "non-ground" strikes that did not make it all the way to the terrain. These non-ground strikes typically include vegetation, buildings, powerlines, and birds …. all valid features to measure, but features which are not required for users modelling ground shapes. Generally this classification is done using morphological filters, i.e. routines which use the shape of the object. Developments are proceeding on including intensity values to help decide whether a feature is a ground or non-ground element. Figure 8 shows both *intensity* and *height* information in an urban scene. The intensity image clearly shows how intensity returns can delineate features not discernible by height alone. The black bitumen roadway is the most striking example.

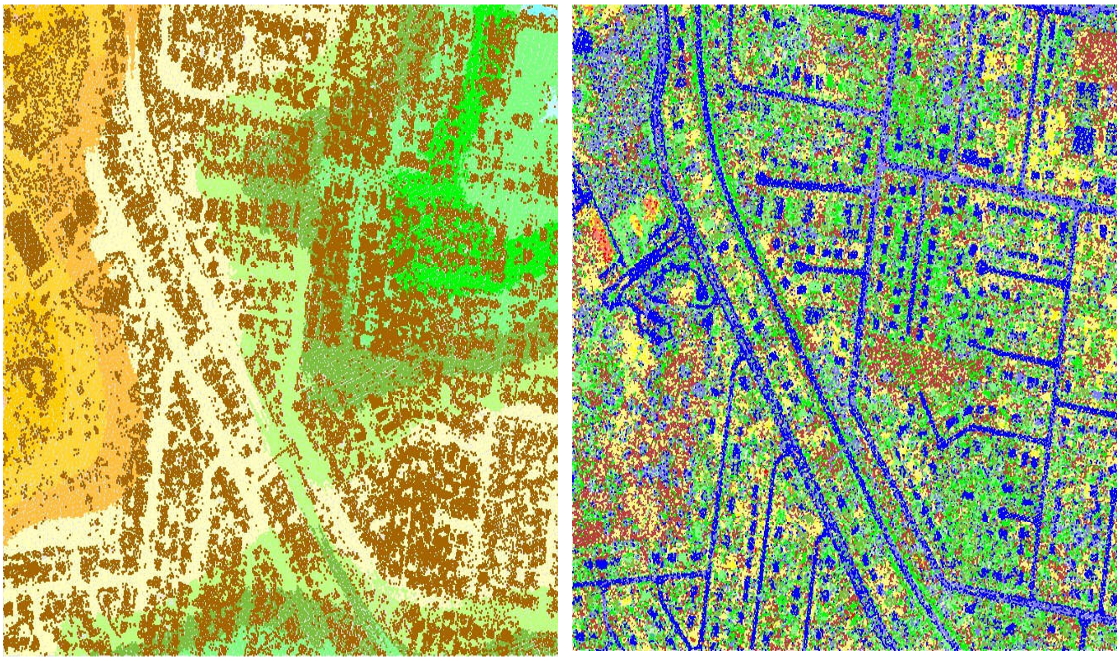

Figure 8 – Urban ALS data colour coded by intensity (right) and height(left)

Intensity returns are also being used in the forestry industry, such as reported by Lovell [2002]. Estimates of foliage cover or foliage amount as a function of height (the foliage profile) can be made by counting the number laser shots within a spatial area that were returned from the canopy, relative to the total number of shots. This method overestimates the foliage amount because of the finite laser spot size – all detected returns are treated equally, even though some may be only partial reflections of the laser beam from small canopy elements. It is possible to use the laser intensity to compensate for these partial reflections to provide better estimates for foliage amount.

This is an interesting application of ALS technology, as its primary use is of the light-penetrating capability of the laser, more than its measuring ability. There is some hope that intensity values may be able to assist in species identification but the little research done to date has failed to find a reliable correlation between species and laser intensity return patterns.

Wide Beam Divergence

Background

The laser is emitted from a narrow aperture in the aircraft and diverges (i.e. gets wider) as it travels to the ground. Early ALS systems were constructed so that the laser beam was as narrow as possible when it reached the ground, so that it measured as precise a piece of ground as possible. The horizontal position of the measuring laser is the centre of the beam; Figure 9 shows that the elevation of the last return can be anywhere within the beam footprint.

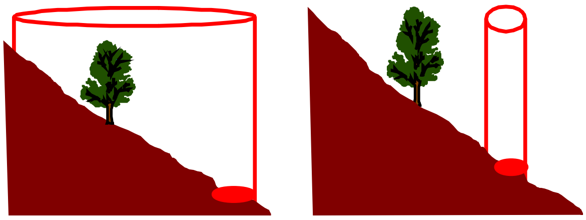

Figure 9 – Wide beam (left) is less accurate than narrow beam on sloping terrain

Current ALS systems have an option to use "narrow beam" or "wide beam" divergence. Typical divergences are 0.2 milliradians and 0.8 milliradians, which equate to a laser footprint diameter of 0.24m or 0.96m from an altitude of 1200m. Acquisition parameters can be tailored so that the average point spacing is equal to the laser footprint diameter; i.e. so that the laser measures the whole surface.

Figure 10 shows how the FIRST and LAST return will be measuring different features, depending on the beam divergence.

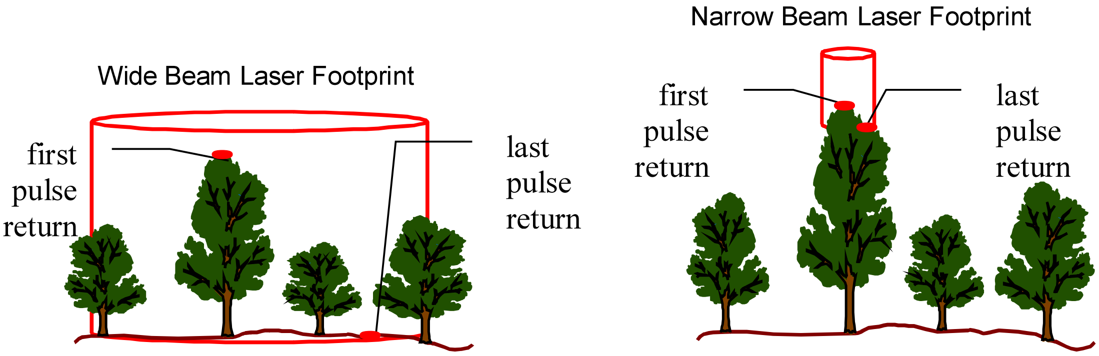

Figure 10 – Difference between Wide and Narrow beam divergence (exaggerated)

Applications

The pros and cons of wide beam divergence are not yet fully understood, and little has been done in utilising the wide beam facility. A recent trial of wide versus narrow beam was conducted over a forested area in New South Wales. The trial involved flying a single pass at each divergence option over a variety of vegetation densities. Acquisition parameters produced an average point spacing of 1.3m. Flown at an altitude of 1100m, beam footprint diameters were 0.22m (narrow) and 0.88m (wide).

The premise was that, in vegetated areas, the wide beam would have more chance of penetrating through the gaps in the canopy. Wide beam would also have more chance of striking the very tops of the trees. Three indices were used to test the premise: percentage of LAST pulse points classified as "ground", percentage of FIRST pulse points classified as "non-ground", and profiles comparing the ground and canopy surfaces measured.

To maximise the ground definition, Table 1 shows that the WIDE beam gives the most number of points. Note that the number of points is not the only criteria for optimising the ground definition; recall Figure 9's explanation how wide beams define sloping terrain less well. This is illustrated in Figure 11, where neither beam produces a better (lower) ground surface. Over the 26Ha Dense Forest trial area, the wide beam terrain model was, overall, just 0.01m lower than the Narrow Beam.

Table 1 – Terrain Definition: Percentage of LAST pulse points classified as ground

	Light Timber	Medium Timber	Dense Timber
Wide Beam	72 %	59 %	45 %
Narrow Beam	68 %	54 %	38 %

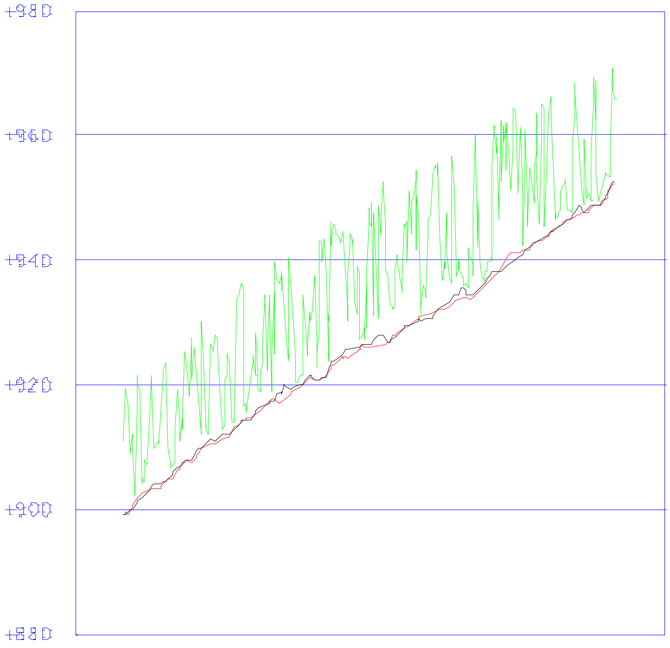

Figure 11 – Canopy model (green), Narrow Beam's terrain model (red) and Wide Beam's terrain model (black) in Dense Timber

To maximise the canopy definition, Table 2 shows WIDE beam gives the most number of most "non-ground" points. Figure 12 compares the Dense Timber's Wide beam and Narrow beam canopy models to show how the wide beam has generally better defined the tops of the trees.

Table 2 – Canopy Definition: Percentage of FIRST pulse points classified as non-ground

	Light Timber	Medium Timber	Dense Timber
Wide Beam	75 %	91 %	91 %
Narrow Beam	71 %	88 %	87 %

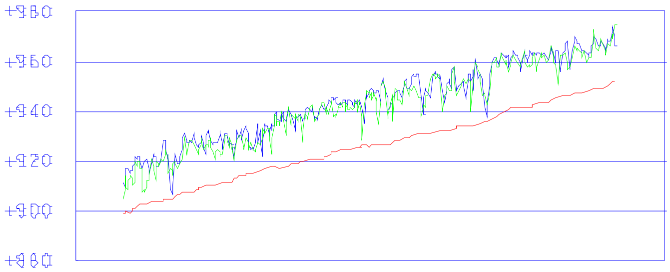

Figure 12 – Terrain model (red), Narrow Beam's canopy model (green) and Wide Beam's canopy model (blue) in Dense Timber

Another use for wide beam divergence that has been applied in Australia in a production environment is in the measuring of power transmission lines. Powerlines are obviously quite narrow, so the chances of striking a wire increase as the beam divergence increases. One does need to be aware that switching to a wide beam divergence spreads the strength of the laser over a wider area. The strength of the reflection from a wide beam is therefore considerably weaker than the concentrated narrow beam. This is particularly relevant to powerline measurement, where the reflectance from the line is quite low in any case. Figure 13 shows an example of ALS points collected using wide beam divergence over a powerline.

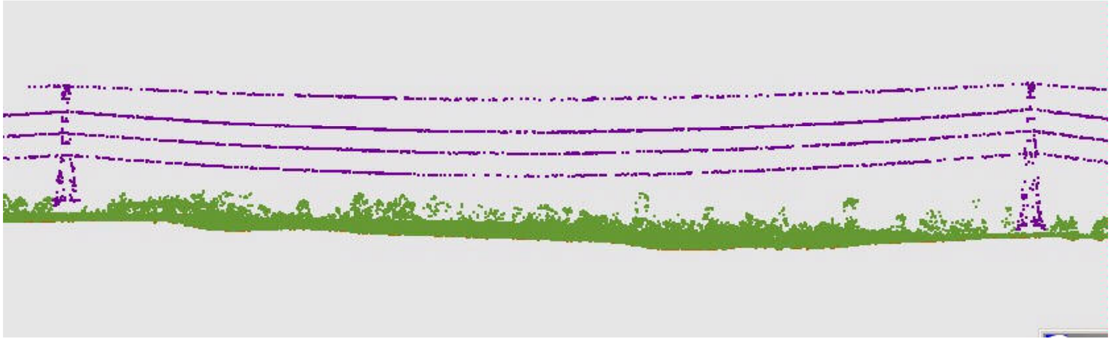

Figure 13 – Powerline, vegetation and terrain measured using wide beam divergence

Concluding Remarks

Airborne Laser Scanning started life as a broad-acre terrain modelling tool. The spatial data community has also taken up the addition benefits of being able to measure non-ground points. That same community however is still finding its way on how to make use of two subtle elements of ALS, viz. intensity returns and beam divergence.

Most ALS practitioners recognise that intensity will add to the value of the spatial data, and beam divergence will add to its flexibility in acquisition. The challenge is now on to develop these benefits and make them available to the wider geospatial community.

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