Airborne and Terrestrial Laser Scanning - Applications for Illawarra Coal

P. Riley
*Illawarra Coal, BHP Billiton*

P. Crowe
*Illawarra Coal, BHP Billiton*
AIRBORNE AND TERRESTRIAL LASER SCANNING:
APPLICATIONS FOR ILLAWARRA COAL

Peter Riley\(^1\) and Peter Crowe\(^1\)

**ABSTRACT:** Laser Scanning technology was introduced to the mapping industry in 1998. The technology enables the acquisition of point data by a laser scanning device mounted either in a fixed or rotary winged aircraft (Airborne, ALS) or placed on ground stations (Terrestrial, TLS). Laser scanning provides a significant increase in data points (e.g., 18 million data points can be gathered per hour) over traditional data capture methods. It also affords cost reductions due to acquisition and processing times when compared to aerial photogrammetry or ground surveying, particularly in areas that are densely vegetated or difficult to access. Due to the relatively quick acquisition and processing time, ability to filter vegetation from the datasets and a simple, flexible, data format, ALS has become an integral extension to the mapping tools available to Illawarra Coal.

**INTRODUCTION**

Airborne Laser Scanning (ALS or LIDAR) was first demonstrated in 1993 and was introduced to the mapping industry in Australia in 1998. The technology is a further development of the Airborne Laser Profilers used by the forestry industry for many years (Hansen and Jonas 2001, Wever and Lindenberger). The technology involves the acquisition of three dimensional ground point data by utilising a laser scanning device operating at frequencies in the near infra-red. The scan direction is orthogonal to the flight path. The unit is mounted in a fixed or rotary winged aircraft flying at altitudes of up to 1000 m. Spatial position is controlled by kinematic dual frequency GPS and the airborne platforms attitude is monitored by the use of an inertial navigation or measuring system (INS/IMU).

The technology can produce data coverage over a large area very rapidly and in terrain that would preclude aerial photography or ground surveys. The ALS acquisition can also occur at night or under cloud in low light if required. The need for a spread of three dimensionally surveyed ground control points in the form of aerial targets is also unnecessary. It is necessary however to provide some ground truth correlation but this can be achieved post survey and in areas of the survey that are easier to access.

The mining industry has traditionally used ALS for use as an exploration broad acre terrain modelling tool. It has also been utilised in new mine site planning and design. In the open cut environment it has been used for slope and stability assessment. The ease of acquisition and rapid processing has made it useful in overburden stripping and volume determination. It has proved to be useful in repeat surveys for environmental monitoring and more recently it has been applied in subsidence monitoring using isopach analysis to detect surface changes.

Illawarra Coal has utilised ALS data to produce GIS layers that, in combination with other data (e.g. Aeromagnetic surveys), can enhance the interpretation and presentation of selected surface features that may be of geological significance to mine planning.

Data sets derived from ALS produce Digital Elevation Models (DEMs). These are used in analytical operations such as slope and aspect determination and surface modelling. These data sets can be filtered to create Digital Terrain models (DTMs), Triangulated Irregular Networks (TINs) and contour lines (at varying intervals depending on requirements). Regular grid products such as raster coverages and datasets that facilitate the monitoring of change management in the man-made and natural environments can be created.

ALS does not produce imagery but most operators will provide a digital image (from conventional cameras) if requested. It is possible however to produce a true-to-scale image of the surface by applying a greyscale reading to the "intensity" of the return signal. Figure 1 shows that like-features such as roads can be extracted from the dataset based on the intensity value.

---

\(^1\) BHP Billiton, Illawarra Coal
The laser beam operates by sweeping the terrain in a swathe to deliver a point cloud. Depending on the requirement, point data can be collected at spacings from sub-metre to 10 metres. Swathe widths are generally up to 700 metres.

When acquiring data in densely vegetated areas, the laser (operating at 1.04 micron wavelength) will receive multiple returns from single pulse travel which will capture tree tops as well as ground. Algorithms have been written to determine which points represent the ground or non-ground. This technique can allow discrimination of vegetation or specific features such as transmission line conductors and tree height. Illawarra Coal have utilised this data in the selection of exploration drill sites that require rigs to be airlifted.

The manufacturers stated accuracy of the ALS positioning is in the order of 10 - 15 cm (rms) in the vertical and 50 - 100 cm (rms) in the horizontal. Illawarra Coal has conducted ground survey checks of specific points and have identified that the standard deviation of the results is within these limits. To obtain this accuracy however a GPS reference base station must be within 50 km of the operating aircraft.

**TERRAIN MODELLING**

ALS technology essentially provides only one product. That is, a point cloud describing the earth surface (Maas, 2001). To successfully describe the earth’s surface each point must have three dimension values, that is, X, Y & Z. The ALS data also has an additional observable, the intensity value of the reflected signal. This can be used to extract features based on the intensity of the return beam. Data produced from ALS surveys are in digital format delivering Easting, Northing, and Height values of each laser target. This simple data format allows for ease of data flow into software to produce a wide range of models and data products. Typical software includes Geographic Information Systems (GIS), Computer Aided Design (CAD) and other industry specific modelling software such as Minescape.

The software typically takes the point data and employs an algorithm to create a model of the earth’s surface.

These models can be continuous surfaces such as a TIN, shown in Figure 2 or Raster, Figure 3, or a Digital Elevation Model (DEM) such as a regular point grid or contour lines. The operator can specify cell size or grid spacing and interpolation method. These products then form the basis for further investigation and analysis of the environment in which mining will take place.

The resultant products can then be used to visualise the surface of the earth, calculate earth movements from repeat surveys, calculate drainage patterns for watersheds or create linear profiles. Figure 4 below shows a surface profile between two points to assess line of site.

The scanning beam from the ALS transceiver cannot initially distinguish between ground points and other points above the ground such as trees, buildings or power lines. Sophisticated algorithms must be applied to the data to separate ground from other objects (non-ground). The non-ground points can be used to identify and visualise the objects on the surface, such as the tree canopy, buildings or powerlines (Figure 5).

The ability to quickly filter ground from non-ground points is one of the many advantages of ALS over traditional aerial photography. For the mining industry this is beneficial because the shape of the surface can be benchmarked before any mining has taken place.
Fig. 2 - Triangular irregular network (TIN) of the Mt Kembla area, produced in ArcGIS by BHP Billiton Illawarra Coal

Fig. 3 - A raster surface over approximately the same area as above. Used more often for surface calculations and the creation of other products than for visualisation. Produced in ArcGIS by BHP Billiton Illawarra Coal
Using a technique called Residuals Mapping, geologists can identify surface features that may otherwise go undetected when using aerial photography or small scale contour maps, or even field visits. The process involves taking the ALS point dataset and applying smoothing interpolators to the surface. This eliminates irregular changes in grade.

The smoothed surface is then subtracted from the original dataset (Figure 6) leaving only those parts of the surface that varies by a small amount (residuals) from the general topography. Sometimes these residuals form patterns (Figure 7) that may indicate underlying geological structure.

Illawarra Coal has used this technique to model surface lineaments associated with dykes. This method creates efficiencies in the planning and execution of exploration work by accurately targeting likely locations before the team enters the field.
ENVIRONMENTAL DEFORMATION AND MONITORING

Many groups and authorities in the community are vitally interested in the effect that mining activities have on infrastructure and the natural environment. Public authorities such as the Department of Primary Industry (DPI) and the Dam Safety Committee (DSC) monitor and regulate the mining activities in the Southern Coalfield, while community groups watch carefully the effect on their local environment. The issues are often emotive and much effort is invested by all stakeholders to ensure that sufficient, pertinent and reliable data is collected.

In the Illawarra and Macarthur regions, a major issue to stakeholders is ground subsidence as a result of Longwall Mining. Subsidence can potentially affect infrastructure such as gas and water pipelines, roads and houses, as well as the natural environment, particularly river beds and cliff lines.

Data is regularly captured in sensitive areas in order to monitor and report to the major stakeholders. Traditionally this data has been collected by field survey or to a lesser extent by aerial photography. The field survey data capture is cheaper than aerial photography but is limited spatially due to the time to acquire the data and surface access restrictions. Photogrammetric methods are costly and still need tight ground control to be accurate enough to achieve the desired tolerances. Both of these methods are also restricted by weather and the environment (e.g. the rugged terrain and thick rain-forest of the Illawarra Escarpment).

An ALS survey is ideally suited to the data capture requirements in these rugged and densely vegetated environments. By utilising ALS to monitor subsidence movement Illawarra Coal can provide a data set to their stakeholders within a reduced time-frame and on a much larger scale than could ever be achieved by conventional surveying techniques.
A recent study conducted by Illawarra Coal, in conjunction with the University of Wollongong, demonstrated the potential benefits of ALS data for subsidence mapping (Palamara et al 2005).

In the study, the results of two pre-mining ALS surveys were compared to a post-mining survey to map the extent and magnitude of subsidence in the rugged and heavily wooded landscape. Figure 8 above shows the terrain immediately west of the Illawarra escarpment.

The results of the study, Figure 9 below, showed that the mean vertical error was well within acceptable limits for assessing regional subsidence movements due to coalmining operations. The figure below shows the extent and magnitude of the subsidence only. It does not show the true shape of the topography.

The study concluded that the assessment of watercourses, steep slopes and cliff areas should be treated with caution during height change analyses using ALS because the horizontal accuracy of ALS is generally not suitable for the accurate mapping of steep or narrow features (French 2003 in Palamara et al 2005).

**CONTOUR MAPPING**

The creation of contours over areas of more than a hectare or two has traditionally only been available using photogrammetric methods. Providing contour maps to the mining industry, surveying companies and government agencies is an expensive exercise and contours with intervals of less than 10 metres have long been on the wish lists of most mining companies.

The ability to create engineering contours ‘on demand’ for areas of the customer’s choosing enables rapid response to the requirements of the exploration program or changing business needs. ALS point data, in conjunction with appropriate software, allows such flexibility.
Fig. 9 - Subsidence model showing exaggerated magnitude and location of subsidence. The model was produced in Surfer 8 using a subtraction algorithm.

Fig. 10 - One metre contours over part of Appin NSW. Created in ArcGIS 3D Analyst

Caution should be exercised in the creation of contours. While the software makes it possible to create contours with an interval as little as 0.1 m, the data may not be designed to perform to that accuracy. It is essential that the survey be designed to meet the requirements of the task.

High resolution surface contours, in the order of 1 metre, over proposed mining areas, Figure 10 above, are becoming the desired mapping requirement for designing future exploration activities. Geologists are able to look at the surface, stripped bare of all vegetation, and identify surface features such as outcrops or depressions that may indicate an underlying geological structure. During field trips these features can then be found with a high degree of confidence using coordinated positioning by means of a hand-held GPS.
High resolution surface contours contribute significantly to the creation of accurate predictive borehole logs. A predictive borehole log is required before a borehole is drilled and generally modelled on data from adjacent existing boreholes. These logs provide a variety of information for drillers, geologists and planners about the substrata horizons or conditions that may be encountered during drilling.

**TERRESTRIAL LASER SCANNING**

Terrestrial Laser Scanning (TLS) uses the same principles as ALS, except that it is ground based. Locating the scanner on the ground gives some distinct advantages for capturing discrete objects from multiple angles.

These systems can measure several thousand points per second allowing for data sets to be collected far in excess of that which could be obtained by traditional surveying or photogrammetric techniques.

TLS is most useful for capturing small (relative to those captured from an aircraft) irregular objects such as buildings, earthworks and landforms such as cliff faces which can be profiled and monitored during mining.

Illawarra Coal has successfully used TLS for monitoring and documenting natural structures and sites influenced by long wall mining.

The TLS surveys can gather information in a non-invasive manner from a safe location. Traditional surveys require people to disturb sensitive areas or subject themselves to dangerous work environments to obtain the required data. The data sets are delivered with high accuracy.

The laser is classified as a Class 2, green laser which is safe to operate indoors and outdoors and therefore does not impede ongoing work in the vicinity. The instrument can be operated in any lighting conditions.

Other applications this technology is useful for include:

- Surface modelling and volume calculations
- Cavity measurement (e.g. Aboriginal rock art sites)
- Slope stability studies
- As-built surveys (including detailed measurements for fabricating plant and machinery that may not have engineering drawings)
- 3D visualisation of structures

An important recent project was the monitoring of a site on the Georges River near Appin in NSW. This site is significant to the local community and it was important to monitor and record changes due to undermining. The TLS scanner was deployed on 20 stations around the site, Figure 11, and data was captured and integrated into a model to be used for analysis.

Analysis algorithms are the same as those used with ALS data. That is, cleaning the data by removing any extraneous points, and then comparing multiple epochs to measure changes.

After cleansing and integration, as shown in Figure 12, the data can be displayed and analysed with various software packages. Typical outputs include cross-sections of the structure, in this case overhangs and channels, contour maps and residuals maps showing where change has occurred. The finished model was also overlaid with digital photography to provide presentation material for community consultation.

**AERIAL IMAGERY**

ALS technology does not produce conventional imagery as one of its outputs. It can however, be operated in conjunction with other sensors such as large format analogue and small format digital cameras, thermal and multi-spectral sensors, satellite and video imagery to produce complimentary datasets (Earls and Jonas 2004). The combination of these various products with ALS data, Figure 13 below, results in a very powerful product. While it is not essential that data from different sensors is captured simultaneously, the addition of a standard or digital camera during the ALS survey can also offer significant cost savings. Unfortunately this is not always possible due to the often different acquisition parameters of the two technologies (Earls and Jonas 2004).
Fig. 11 - Un-integrated raw TLS data, displayed using intensity values to give an image-like result

Fig. 12 - The completed model of the site
CONCLUSION

Mining companies now operate in an era of increased regulation and public scrutiny. It is essential that they investigate innovative technologies that offer fast, reliable and comprehensive data capture methodologies. Airborne and Terrestrial Laser Scanners meet these requirements, providing flexible, rapid, cost effective and high quality data sets that enhance the mapping and reporting capabilities of the company.

Illawarra Coal has found that ALS and TLS are powerful tools with many proven and potential applications. They compliment, rather than replace a wide range of existing data capture methods and have proven that they add value to the interpretation and presentation of existing data. Ongoing developments such as the recording of the full waveform of the signal can only increase the potential of this technology.

REFERENCES


