AIRBORNE LASER SCANNING

OR

AERIAL PHOTOGRAMMETRY

FOR THE

MINE SURVEYOR

by

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ABSTRACT

Airborne Laser Scanning (ALS) was first introduced into Australia in 1998 and has since proved its worth as a broad-acre terrain-modelling tool. But is this technology relevant to the spatial data needs required in the Australian mining industry? This paper discusses the pros and cons of the ALS system in comparison with photogrammetry, the current broad-acre data acquisition technique utilised by most mining operations. The findings are that ALS is not going to revolutionise data acquisition in Australian mines, but that it does provide a useful contribution to the mine surveyor's toolkit. To complete the comparison, recent advances in photogrammetry are also discussed.

INTRODUCTION

Today's mine surveyor is required to provide an ever-increasing number of services to his or her domain, often with ever decreasing budgets. The need therefore exists to utilise the most appropriate technology to meet the project requirements within the available resources. Since the early 1980's, the analytical stereocompiler has been the workhorse for broad-acre spatial data acquisition tasks including exploration mapping, regular mine planning and stockpile measurements (Byrne, 1997). It has also played a lesser role in subsidence monitoring, environmental lease statistics and infrastructure mapping.

Since 1994, a new airborne terrain modelling technology has been available to the surveying industry. The term "Airborne Laser Scanner" (ALS) evolved as the hardware utilised in the aircraft is a logical advancement of the Airborne Laser Profilers used primarily by the forestry industry for many years. Other titles attributed to the same piece of hardware include "LIDAR" (the term favoured in the United States), and "Airborne Laser Terrain Mapper (ALTM)", the brand name used by the major hardware manufacturer in this field.

Whichever term adopted, this laser technology is offering an alternative to traditional photogrammetric acquisition.

THE TECHNOLOGY

The three fundamental components of an ALS system are shown in Figure 1.

1. Aircraft position is determined by kinematic dual frequency GPS, typically at 1 second epochs;

2. aircraft orientation or attitude is continually monitored by a sensitive Inertial Reference System (IRS), typically at 50 times per second; and
3. the terrain measurement device emits a number of discrete laser beams (typically 5000 to 25000 per second), measuring the time taken for the beam to reflect from the ground back to the aircraft.

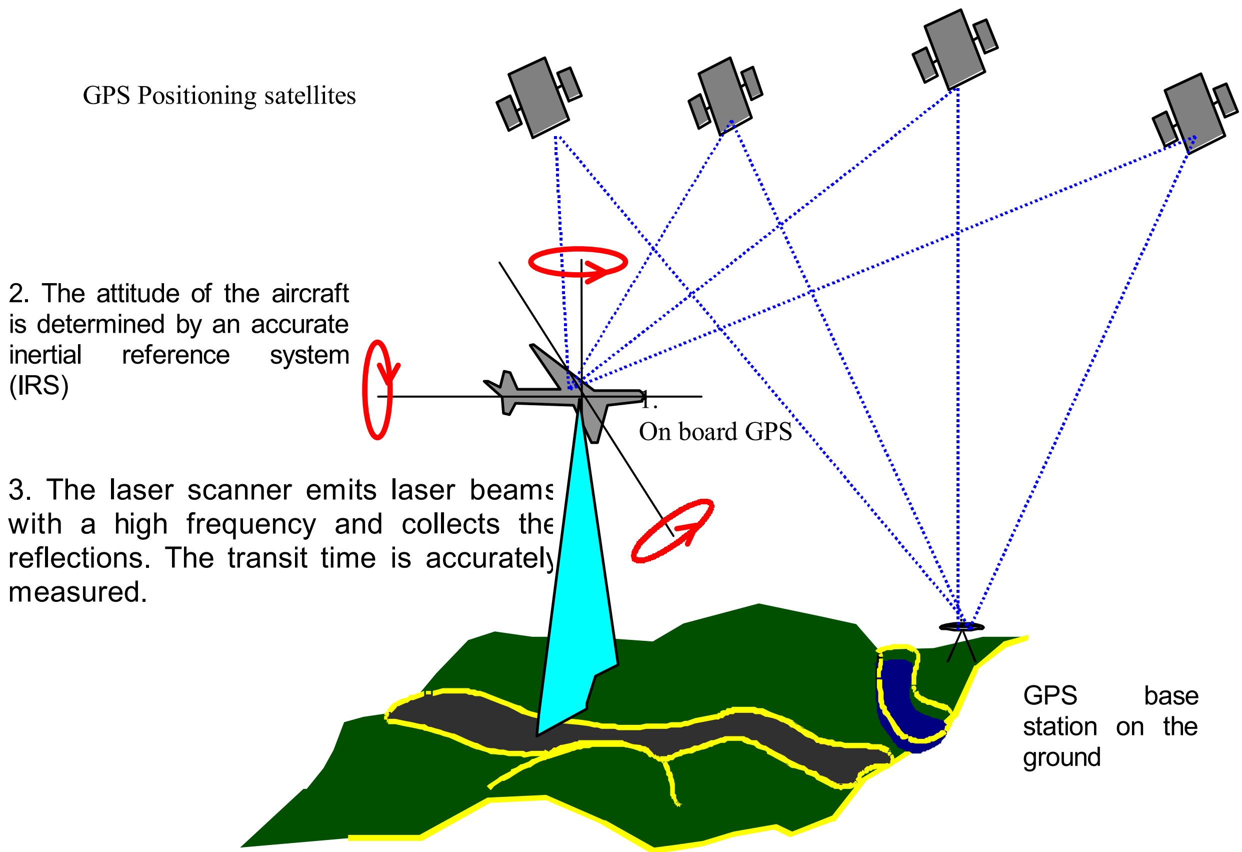

Figure I – Three components of the ALS system

The laser beam is directed in a swathe across the ground by a rotating mirror. Post-processing software combines the scanner's position, its attitude and the distances measured to compile a digital elevation model.

The operational parameters of laser frequency, swathe width, flying height and aircraft velocity can be tailored to meet the optimum point density for each project. Typically this can range from an average point spacing of 10 metres down to 1 metre or less, covering a swathe width of up to 700 metres. The scanner emits a laser of 1.04 micron wavelength which is not in the visible spectrum and is eye-safe. The scanner automatically shuts down if the system receives a return signal corresponding to a range of less than 300 metres.

At a typical operating altitude, the emitted beam is approximately 300mm in diameter at the end of the swathe. If operating over vegetation, some of the return signal is reflected from the top of the canopy, some penetrates to the canopy substrata and some penetrates to the ground. Various scanners are configured to record the distance from the *first* reflection it receives back ("first pulse"), from the *last* reflection it receives ("last pulse") or some can record multiple returns from the one emitted pulse.

An integral part of the ALS solution involves software that applies morphological filters to separate the raw ALS strikes into "ground" and "non-ground". The software requires the operator to define the classification characteristics such as terrain angle, search distance and expected deviation. It uses a recursive algorithm based on changes in slope to determine which laser strikes meet those criteria and should be called "ground" and which do not ("non-ground").

Further processing can categorise "non-ground" points into more specific datasets. These could include "pylons", "conductors" and "vegetation" for powerline surveys; or "crowns" and "tallest trees in a cell" for forestry modelling.

GENERAL OVERVIEW

Many mine surveyors are familiar with photogrammetry as a broad-acre data acquisition tool. The following general overview of ALS is presented by comparing the features of ALS against aerial photogrammetry. Table 1 summarises the features of any broad-acre data acquisition survey; a brief discussion on the key differences and similarities follow the table.

The authors are most familiar with the Optech range of laser scanners, more specifically the Optech 1020 and 1210 models, although most of the observations apply to ALS systems generically.

	Airborne Laser Scanning	**Aerial Photogrammetry**
Accuracy / precision	♦ 0.15m to 0.20m RMS	♦ relative to photoscale, 0.08m to 20m
Resolution	♦ typical point spacing 3m	♦ resolution defined by project requirements
Ground support	♦ requires base station within 50km ♦ ground-truth points provide survey redundancy	♦ ground control required ♦ may be supplemented with Skycontrol
Data acquisition	♦ can be done under cloud and at night	♦ must be done during the day, preferably without cloud shadow
Timing	♦ sizeable datasets available within a week or two	♦ sizeable datasets available within a month or two
Data format / Classification	♦ random spot heights ♦ semi-automatic classification	♦ vector line strings ♦ manual classification
Penetration	♦ data points measured under trees	♦ operator interprets the ground under trees
Imagery	♦ separate sensor required	♦ byproduct

Cost	♦ high startup cost	♦ proportional to area

Table 1 - Features of Airborne Laser Scanning versus Aerial Photogrammetry

Accuracy / Precision

The inherent accuracy of a single ALS spot height is in the order of 0.15m to 0.20m rms. This assumes that the GPS base station is within 50km of the operating aircraft, that a successful kinematic GPS adjustment was possible and that the equipment is in correct calibration. The accuracy of the terrain model formed from an ALS dataset is therefore a function of the point spacing of points classified as “ground”, and the regularity of the terrain. If a project does not require this level of accuracy, there is relatively little one can do to reduce the cost of the survey. This is in stark contrast to photogrammetry where accuracy is a function of ground control accuracy and photoscale. It is important to realise that, in most cases, photogrammetric accuracy refers to points acquired "on clear ground". The accuracy of photogrammetric data acquired on unclear ground (ie, heavily vegetated areas) is generally unknown.

Resolution

Like accuracy, there is much less flexibility in defining the resolution of an ALS survey than for a photogrammetric survey. One can fly higher and faster to decrease the point density of ALS, but only within the narrow bounds of hardware capabilities. The resolution of a photogrammetric dataset is much easier to control and is usually an important component of a project’s specification. The ability to depict changes of grade, spot height intervals and other topographic features, all within pre-defined parameters, are advantages of the photogrammetric environment.

Ground Support

ALS requires only a single GPS base station logging at 1 second epochs within 50km of the operating aircraft. That is what it *requires*, but conventional surveying principles dictate that a certain level of redundancy be introduced. Typically this involves a field survey team coordinating 100 ground-truth points in a clear flat area within the project. These points are used to check for gross errors in the ALS survey and to determine the achieved accuracy of the ALS survey. The ground-truth points also allow the ALS data to be redatumed onto the site's height datum. As it is GPS based, the ALS survey is acquired and computed in WGS84 ellipsoidal heights. To return the ellipsoidal heights to orthometric heights (eg. AHD), the usual practice in Australia is to utilise Ausgeoid. In reality however, this often requires a site-specific datum shift of a few points of a metre to ensure that the ALS survey fits with the project's site datum.

The 100 ground-truth points can all be contained within a single area anywhere within the ALS data coverage. Conversely, ground control for photogrammetry is usually required in pre-determined positions, spread right across the site, and often extending beyond the mine site's area of control. In recent years, the number of ground control points required in broad-acre projects has significantly decreased, by recording the positions of photo centres at the time of exposure ("Skycontrol") and incorporating these into the photogrammetric block. Field test points are always recommended to validate the photogrammetric dataset.

Data Acquisition

Although the laser will not penetrate clouds or operate in rain, the ALS system can be used under clouds and at night. Operationally, this allows the ALS data acquisition to proceed with fewer interruptions than aerial photography. Operating at night offers a degree of flexibility for time-specific site requirements such as tidal flows, blasting/dust hazards, and prevailing cloud conditions.

Aerial photogrammetry requires daylight hours with sun angles high enough to prevent shadows obscuring salient features.

Timing

Data delivery of large terrain models acquired by ALS can be far quicker than comparable datasets defined by aerial photogrammetry. Last Christmas, AAM Geodan delivered an ALS survey over 18,000 hectares of rugged, densely vegetated mountain country in just 13 days after data acquisition (Powell, 2000).

As the size of the dataset decreases, so too does the timing advantage offered by ALS. Aerial photogrammetry is regularly used to define stockpile volumes where volume reports are sent to site 2 days after acquisition. Assuming that the volume computations are still done back in the office, stockpile volumes by ALS would not be available any quicker. The ALS data reduction and volume computations could be done in the field, but with significant cost implications.

Data Format / Classification

Perhaps the most significant difference between ALS and aerial photogrammetry is in the deliverable product. ALS is an automated process where literally millions of spot heights are thrown across the project area to define the terrain shape. These spot heights can be subsequently thinned to remove those points that do not contribute to the terrain definition, but the raw product is a collection of random spot heights. Contrasting this is the traditional photogrammetric product where a trained operator manually digitises and codes the data at the time of acquisition. The operator joins like points to form vector strings such as highwall crest, drain or embankment. These vectors feed easily into mine planning or CAD software packages.

Penetration

As previously stated, ALS has an advantage over aerial photogrammetry in areas covered by vegetation. For the photogrammetrist to measure under trees, the piece of ground must be visible on two adjoining aerial photos and not be covered by shadow. The rule of thumb for ALS is that, if you can walk through the forest and see daylight above, that is the proportion of points which will penetrate through the canopy and strike the ground.

In the mining industry, this feature of ALS would be most relevant in the exploration phases where terrain models are required underneath vegetation.

Imagery

There is no imagery produced from the laser system itself, but many ALS aircraft incorporate a separate imaging system to complement the laser terrain model. Sensors in regular use include videos, digital cameras and conventional metric survey cameras.

Cost

When compared to field surveying, aerial photogrammetry has always carried the stigma of carrying a high startup cost where the first terrain point measured can be quite expensive, but subsequent points become more affordable. The same can be said of ALS in Australia, where the capital cost of the equipment demands that the time taken to ferry the aerial survey unit to the site be recouped in a mobilisation charge. Conversely, the huge rate of data acquisition ensures that large tracts of land can be defined very rapidly. A recent example involved a project in NSW where 1400 km^2 was defined with 300 million data points in just 3 days.

Factors that affect costings in ALS surveys include:

- site location - which affects ferry times;
- project timing - can the survey be timed to coincide with other work in the area?;
- project shape - long rectangular areas are more efficient to capture than narrow windy ones where the aircraft spends more time lining up than actually over the site;
- required point density - higher point densities demand narrower swathes and slower aircraft;
- post-processing required - an open cut mine where most laser strikes could be classified as "ground" would be cheaper than a heavily vegetated exploration lease where the client requires the laser strikes divided into ground, canopy top and non-ground;
- accuracy required - more demanding accuracies (generally below 0.20m rms) require closer attention be paid to the overall error budget. Issues of GPS adjustment, geoid modeling, point densities, etc. become more critical.

Because much of the cost of an ALS survey is in positioning the aerial survey unit, significant increases in the size of the survey area are not always reflected in significantly higher charges. This is particularly true if the project area is enlarged simply by increasing the length of the survey lines. This is in contrast to photogrammetric data acquisition where the cost of the survey is much more proportional to the extent of the project. Examples of this are provided as a Case Study in the following section.

CASE STUDY

To bring together the features listed in Table 1, consider a hypothetical open cut and underground mine located 500km from Sydney. On a typical hectic day on the job, three different departments approach the mine surveyor with requests to obtain spatial data of three different parts of the mine. The requirements are:

1. **The Resource Assessment Department** at head office needs a terrain model of the 25,000ha Mining Development Lease (MDL) to the south of the current operations. The project area is approximately 16km square. Half of the area is covered with dense eucalypts, while the current property owners use the other half as a successful and highly profitable horse stud. The Senior Geologist would like the data to a standard capable of providing conventional 1:1250 cartographic plans with 1m contours.

2. **The Engineering Department** on site needs their annual mine update done. The mining lease covers 15km x 7km (10,500ha), but they estimate that only 2800ha of the mine has changed since the last aerial survey. Apparently the spoil rehabilitation has not been overly successful, with several minor slips last year and water ponding a bit of an issue in certain areas.

3. **The Legal Department** is again worried about regional subsidence, possibly attributable to the underground mine to the north of the main pit. The last panel subsidence survey was done five years ago and it is time to see what has changed in that period. The area extends over 6km by 7.5km of open rolling pastures; the ongoing subsidence programme requires the data to be accurate to 0.2m rms.

What are the issues needed to be considered when evaluating how to satisfy these three project definitions within the Departments' time and cost budgets ?

1. Resource Assessment Department

The photogrammetric procedure to meet this project specification could involve:

- Fly 89 frames of 1:15,000 colour aerial photography
- Coordinate perspective centre coordinates of the 89 frames by kinematic gps at the time of exposure
- Place and coordinate 15 targeted ground control points, five of which need to be within the land-owner's property
- Aerotriangulate the photogrammetric block
- Stereodigitise breaklines and spot heights and all visible detail
- Derive 1m contours from the breaklines and spot heights in open areas
- Derive 5m approximate contours in the heavily timbered areas
- Deliver DXF files containing detail, DTM and contours, plus colour contact prints of the aerial photography
- Estimated delivery time from date of photography: 12 weeks
- Approximate cost: $120,000

The Airborne Laser Scanning procedure could involve:

- Fly 41 ALS swathes at 10,000 Hz with a nominal ground point spacing of 2.5m

- Coordinate 100 ground-truth points in an easily accessible area of the MDL
- Classify the data into ground and non-ground strikes
- Thin the 41 million spot heights gathered to those required to define the terrain
- Derive 1m contours in open areas and 2m contours in the heavily timbered areas
- Fly 8 frames of 1:55,000 colour aerial photography
- Place and coordinate 4 targetted ground control points
- Scan and orthorectify the photography on the ALS terrain model; Mosaic the images
- Deliver xyz ASCII files of the terrain model, DXF files of the derived contours and copies of the orthophotomosaic (digital and hard copy)
- Estimated delivery time from date of ALS acquisition: 3 weeks
- Approximate cost: $85,000 for the ALS and $10,000 for the imagery and mosaics.

Significant Differences:
- Photogrammetry provides vector detail strings instead of digital imagery
- ALS gave a better terrain definition under the vegetation
- ALS solution did not require access to the land owner's property
- ALS 20% cheaper and 75% quicker

2. The Engineering Department

The photogrammetric procedure to meet this project specification could involve:
- Fly 4 runs of black-and-white aerial photography covering all mined areas
- Use the existing permanent ground control targets
- Aerotriangulate the photogrammetric block
- Stereodigitise breaklines and spot heights and all visible detail within areas of change
- Derive contours from the breaklines and spot heights (5m interval in the spoil, 2m elsewhere).
- Deliver DXF files containing detail, DTM and contours, plus contact prints of the aerial photography
- Estimated delivery time from date of photography: 6 weeks
- Approximate cost: $43,000

The Airborne Laser Scanning procedure could involve:
- Fly 25 ALS swathes at 10,000 Hz with a nominal ground point spacing of 2.5m
- Coordinate 100 ground-truth points in an easily accessible area of the site
- Classify the data into ground and non-ground strikes
- Thin the 17 million spot heights gathered to those required to define the terrain
- Derive contours (1m intervals, wherever required)
- Fly 5 frames of 1:35,000 colour aerial photography
- Use the existing permanent ground control targets
- Scan and orthorectify the photography on the ALS terrain model; Mosaic the images
- Deliver xyz ASCII files of the terrain model, DXF files of the derived contours and copies of the orthophotomosaic (digital and hard copy)
- Estimated delivery time from date of ALS acquisition: 2 weeks
- Approximate cost: $43,000 for the ALS and $8,000 for the imagery and mosaics.

Significant Differences:
- Photogrammetry provides vector detail strings instead of digital imagery

- Photogrammetry was better suited to only measuring those areas which needed updating
- ALS better defined the spoil areas
- ALS 18% dearer and 66% quicker

3. The Legal Department

The photogrammetric procedure to meet this project specification could involve:

- Fly 15 frames in 3 runs of black-and-white aerial photography
- Coordinate perspective centre coordinates of all frames
- Target and coordinate 12 ground control points
- Aerotriangulate the photogrammetric block
- Stereodigitise breaklines and a regular grid of spot heights (25m separation)
- Derive isopachs and calculate volume differences between the current surface and the previous surface
- Deliver report on extent and magnitude of differences between the surfaces
- Estimated delivery time from date of photography: 6 weeks
- Approximate cost: $19,500

The Airborne Laser Scanning procedure could involve:

- Fly 15 ALS swathes at 10,000 Hz with a nominal ground point spacing of 2.5m
- Coordinate 100 ground-truth points in an easily accessible area
- Derive isopachs and calculate volume differences between the current surface and the previous surface
- Deliver report on extent and magnitude of differences between the surfaces
- Estimated delivery time from date of ALS acquisition: 2 weeks
- Approximate cost: $21,500.
- As the size of the project area increases, the ALS will become more cost competitive. Table 2 provides indicative prices as the size of the area increases.

Project Area	Aerial Photogrammetry Cost	ALS Cost
6 km by 7.5 km	$ 19,500	$ 21,500
6 km by 12 km	$ 22,800	$ 23,200
6 km by 15 km	$ 29,600	$ 23,400

Table 2 – Typical costings illustrating how costs increase with the project size

Significant Differences:

- Both techniques require control to be brought in from “stable” areas
- ALS provides a denser array of spot heights
- ALS 10% dearer and 66% quicker
- As the size of the project area increases, ALS becomes more cost competitive.

WHERE TO NEXT

Both aerial photogrammetry and Airborne Laser Scanning are evolving at a significant rate. That is to be expected of ALS, as it is only just emerging from its informative years and is now evolving to fit the market niches to which it is best suited. But this is also true of photogrammetry, where the grand old lady of data acquisition is reinventing herself through the advent of “softcopy photogrammetry”.

Aerial Photogrammetry

Softcopy photogrammetry involves replacing the analogue photograph with a digital equivalent, and allowing computer software to automate many of the time-consuming techniques currently employed. Currently, the process involves capturing the imagery using conventional film-based cameras and scanning the photos into the computer. But this too is changing with digital aerial cameras to be released into the market within the next few years.

The most significant advancement offered by softcopy photogrammetry is “auto-correlation”. This technique involves using complex image matching algorithms to calculate the height displacement in the image and so compute the height of every pixel. The authors contend that current autocorrelation software is only suitable for terrain definition at the lower end of the market, most notably for orthorectification. It is well beyond the scope of this paper to argue such a view, but the lack of published successes in this field and the fact that few photogrammetric suppliers are using this approach for engineering purposes, stand as stark reminders of where the market sees this technology. However this will certainly change as software improves.

The use of high resolution satellite imagery is set to alter the aerial photogrammetric industry over the next decade. Already, the next generation of satellites boast 1m pixel resolution and they will provide suitable alternatives to high level aerial photography. Over time, the distinctions between “aerial photography” and “satellite imagery” will blur and become irrelevant.

Airborne Laser Scanning

ALS is also advancing on both the hardware and software fronts. Quite predictably, hardware is improving so that more points per second can be measured from higher altitudes. The latest systems can measure more than one distance per pulse, some can also measure though shallow water and some record the intensity of the laser beam returned to the aircraft.

Of more interest are the improvements in software. Projects being actively pursued around the world include:

- improvements in classification algorithms;
- breakline detection, where sharp changes in grade are vectorised into breaklines;
- building detection (Chilton, 1999);

- automatic “block adjustments” where the agreement between swathe overlaps is used to better fit the individuals swathes together;
- post-processing the IRS data by applying Kalman filters to the aircraft’s orientation.

CONCLUSION

Airborne Laser Scanning is a relative new technology, which is now available to the mining industry as an additional tool for the acquisition of spatial information. The ability to acquire accurate data in heavily vegetated terrain, over vast areas, with minimal ground support and in relatively quick time, are all advantages of ALS. However, ALS does not produce a photographic image, vector line strings are not defined and feature coding is limited. All of these requirements are currently fulfilled by the photogrammetric solution. Aerial photogrammetry will continue to play an important role in the day to day activities of the mine surveyor, with ALS being introduced to improve the acquisition of spatial data in terms of decreased turnaround times, quality of data and reduced cost.

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