# EXTENSION OF TOPOGRAPHICAL MODELLING CAPABILITY WITH AIRBORNE LASER SCANNING

D. Jonas
AAM Geodan
11 Wicklow Street
Kangaroo Point Qld 4169
Ph: (07) 3891 1033
Fax: (07) 3891 1050
D.Jonas@aamsurveys.com.au

P. Byrne
AAM Surveys Pty Limited
23 Hamilton Street
Subiaco WA 6008
Ph: (08) 9381 4133
Fax: (08) 9381 6161
P.Byrne@aamsurveys.com.au

6th South East Asian Surveyors Congress
Fremantle, Western Australia
1 - 6 November 1999

**David Jonas B.Surv(Hons), M.Surv.Sc.** has been involved with the acquisition, processing and analysis of digital spatial data with AAM Surveys for over fifteen years. Over the last fifteen months this experience has widened to involvement in Airborne Laser Scanning (ALS). In evaluating ALS technology for the South East Asian region, he has analysed the spatial and classification accuracy of ALS data gathered in Australia. More recently he worked in a European survey office, processing and analysing ALS data in an established production environment.

**Peter Byrne, Hon. FIS Aust.**, is a surveyor and Managing Director of AAM Surveys Pty Limited, a national private surveying and mapping company. His career interests have centred on the application of surveying and information technologies in engineering. Recent publications have been in connection with the Principles of Surveying. He is a Past President of the Institution of Surveyors (1984-85) and Past Vice President of the International Federation of Surveyors (1992-1996).

## ABSTRACT

Airborne Laser Scanning (ALS) is considered as a surface modelling technology. The system is described and the results of a series of recent pilot projects are reported. The strengths and weaknesses of Airborne Laser Scanning are considered, and compared with more established technologies. The primary advantage of ALS is the ability to reliably survey through vegetation and to simultaneously record terrain and non-terrain features such as powerlines and tree canopies. In comparing ALS with other technologies it is found to complement rather than displace.

## INTRODUCTION

Defining the shape of the land in natural or built environments is one of the fundamental tasks of the surveyor. As populations increase; and land use becomes more intense; the need for accurate, detailed and timely topographical information grows.

The physics of topographical surveying methods underwent considerable change since the mid 20th century: steel tapes were replaced with light waves, glass scales with digital encoders, space rod mechanics with collenearity equations. There is no mid 20th century counterpart for autocorrelation or GPS. Yet in its essence, topographical surveying remains unchanged – each survey is a collection ofthree dimensional points – attributed, analysed and processed to define a physical surface to satisfy general or specific user needs.

New non-contact topographical modelling technologies are emerging and gaining support. One such technology is Airborne Laser Scanning (ALS). ALS has been used in Europe and North America for over five years. (Vaughnet al, 1996) (Kost, 1997).

In the following sections some of the first operational trials of ALS in Australia, undertaken in 1998, are described. The results and findings are related to the more established modelling techniques.

## THE TECHNOLOGY

The three fundamental components of an ALS system are shown in Figure 1.Aircraft position is determined by kinematic dual frequency GPS, aircraft orientation or attitude is continually monitored by a sensitive Inertial Reference System (IRS) and the terrain measurement device emits a laser beam with a high frequency, measuring the time taken for the beam to reflect from the ground back to the aircraft. 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 (DEM).

The equipment used for the 1998 trials included an Optech 1020 ALS scanner mounted in an Aerocommander 680 survey aircraft. The Optech 1020 can acquire data up to 5000 points per second over a swathe width of 700 metres from a maximum flying height of 900 metres. The operational parameters of laserfrequency, 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. 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. 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. The Optech 1020 can be configured to record the distance from the first reflection it receives back ("first pulse"), or from the last reflection it receives ("last pulse"). Later models can record first and last returns and can emit more pulses per second. Some instruments can record multiple returns, although utilisation of height information through vegetation is still being explored.

An integral part of the ALS solution involves software which applies morphological filters to separate the raw ALS strikes into "ground" and "non-ground". The software requires the operator to select the terrain type (e.g flat, hilly etc) and nominate the vegetation density. It uses a recursive algorithm based on changes in slope within those points categorised as "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.

In this paper, the term Digital Terrain Model (DTM) is used to refer to a surface defined by ground (terrain) strikes, whereas Digital Elevation Model (DEM) defines a surface encompassing ground and objects and features above the ground.

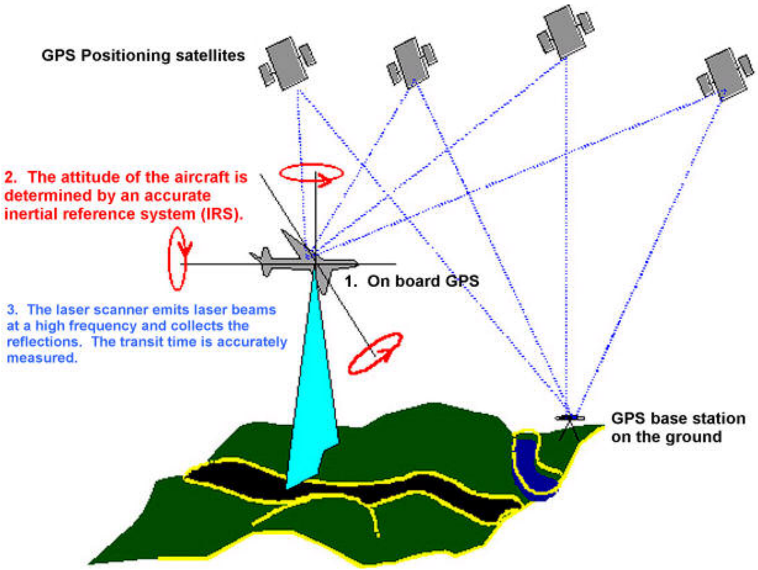

*Figure 1: Three Components of the ALS System*

## 1998 AUSTRALIAN TRIALS

In August 1998, AAM Surveys and Geodan Geodesie of the Netherlands conducted a number of trials. Geodan was selected as a partner through its rigorous approach to the measurement science involved with spatial data capture and its links with TopScan GmbH, the German company which developed much of the software and the algorithms used to process ALS data.

The aim of the 1998 trials was to evaluate operation, practicability and accuracy of ALS under Australian conditions by employing the technology over a range of different applications and environments. Professor Clive Fraser of Melbourne University was engaged to provide an independent technical assessment of the trials and evaluation of the results (Fraser, Jonas and Turton, 1999). From a commercial perspective, the trials also sought to assess the potential market for ALS services in Australia.

During the trials, a diverse range of ALS applications were tested over twenty-four sites in Queensland, New South Wales and Western Australia.

## APPLICATIONS

The following examples of projects have been selected to illustrate the range of potential applications.

### Coastal Zone Management

Coastal zones are typically large isolated areas with difficult access, which makes them uneconomical for field survey methods. They are often unsuitable for photogrammetric surveying because of the difficulty in locating ground control points and the large expanses of featurelessterrain which make accurate stereoscopic pointings or autocorrelation difficult.

Three coastal sites were flown in the 1998 trials to determine the suitability of ALS for coastal zones management in Australia. Russell Island near Brisbane provided a diverse range of coastal zone surfaces to measure, most of which are visible in Figure 2.

A single pass of the ALS aircraft measured:

> Inter tidal mudflats – although the photograph in Figure 2 was taken at high tide, the ALS sortie was purposefully flown at low tide (aerial photography and ALS data can now be acquired simultaneously). The laser response from the mudflats was close to one hundred percent, providing a dense array of points to define the shape and channels inthe inter tidal zone.
>
> Fringing mangroves – the ALS produced a DEM defining the fringing mangroves around the bay. As a part of a regular survey program, this information could monitor the extent and height of coastal mangroves.
>
> Extent of mudflats – the extent of the mudflats is generally concealed beneath the coastal vegetation. ALS data was able to penetrate the mangroves to measure the terrain defining the extent of the inter tidal mudflats. The extent of erosion and accretion could be monitored with a regular ALS program.
>
> Coastal sand dunes – the condition of coastal sand dunes can be monitored by regular ALS surveys as the scanner will acquire a DTM of the dunes as well as recording the height and extent of the vegetation protecting the dunes. Annual ALS surveyshave replaced a photogrammetric monitoring system in Europe, providing more data at less cost. (Chung 1999)

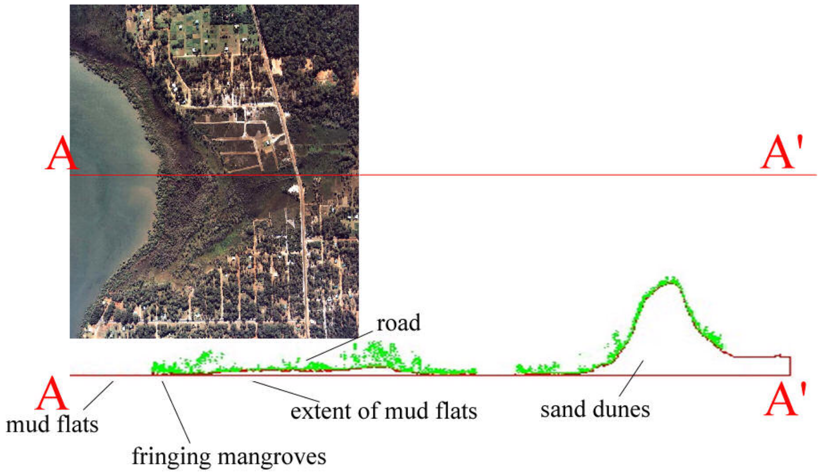

*Figure 2: Russell Island at high tide and ALS profile measured at low tide*

## Powerline Management

Surveying single objects using ALS has been the subject of previous research and trial (Lohr 1999), power transmission lines being obvious applications.

The chosen site is of a high-voltage transmission line in Central Queensland. The purpose of the ALS trial was to assess how well the powerlines, the underlying terrain and the vegetation profile below the conductors could be measured by laser scanning. Successful determination of vegetation clearance illustrates that the ALS technology can be used for routine monitoring of powerlines for reasons such as bush fire mitigation.

The ability to simultaneously measure power conductors and intruding vegetation has not been previously viable. Powerline surveys by ALS are particularly economical when combined with asset management surveys.

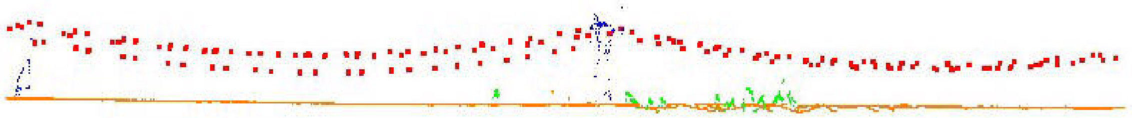

*Figure 3: Profile showing ALS strikes and classification on a powerline*

ALS can be used at the planning and design stages of transmission line development. Many powerlines need to traverse heavily vegetated, inaccessible and steep terrain. The ability of ALS to penetrate dense canopies offers the route locator the ability to obtain a reliable DTM before the route is cleared. A trial in the Gold Coast hinterland showed that a DTM could be acquired in dense timber (see Figure 4) in very steep terrain (slopes >30%).

*Figure 4: Dense Forest & Steep Terrain: Springbrook*

## Forest Management

The forest industry in Australia has shown considerable interest in ALS technology. The industry has been using airborne laser profilers for some time to capture a single line of canopy heights. Eight of the 1998 test sites were flown to meet forestry requirements. Vegetation coverage varied from thin wispy eucalypts and dense sub-tropical rainforest to dense mature pine plantations with complex undergrowth. In several of these sites, ground-truth was available to test the accuracy of the ALS DTM.

The accuracy of the ALS DTM was found to be proportional to the density of the vegetation and the irregularity of the terrain. This could be understood in terms of the success of the classification software. Essentially, every ALS data strike is of a similar accuracy (approximately 0.10 to 0.15m, depending upon the GPS solution and flight parameters). The accuracy of the surface defined by ALS depends upon how successful the classification software is in deducing if the strike is on the terrain, canopy or another surface. Table I shows the ALS accuracy achieved at three of the trial sites, arranged in decreasing accuracies. In each case a small systematic error (or bias) between the ALS data and the ground-truth data was removed before the comparisons.

| Site Description | ALS Standard Height Error (m) |
|---|---|
| Medium eucalypt forest; little undergrowth; reasonably flat terrain | 0.13 |
| Open grassland adjoining a highway; moderate undulations | 0.32 |
| Dense mature pine; complex undergrowth; moderate undulations (see Fig. 5) | 1.04 |

***Table I – Accuracy of ALS DTM compared to field survey heights***

In comparison with other technologies, only ALS and terrestrial surveying can define the terrain beneath medium to dense vegetation. Canopy heights are currently measured from the terrain. Photogrammetry has been tried with limited success and autocorrelation is currently being researched in Tasmania and elsewhere. Both of these techniques are compromised by imaging the canopy from two different points at different times; the difficulty being that foliage moves between exposures and does not present a sharp image from which to measure.

***Figure 5: Airborne Laser Scanning provided DTM with an accuracy of 1m in dense mature pine with complex undergrowth***

As well as providing the terrain shape under the vegetation, ALS can also define the tree canopies. Further processing to identify the "canopy" strikes from those already classified as "non-ground" is possible. Classification software which adopts the method is similar to the process used by forestry surveyors in the field. Software to divide the site into test calls and select the tallest *n* trees within each cell has since been developed. By defining terrain and crowns surfaces, tree heights can be deduced.

It should be recognised that ALS can only provide the spatial component of a forest inventory; other components are required to compile a meaningful inventory. Some of these may be defined simultaneously from other remote sensors mounted in the aircraft. For example, aerial photography can assist in determining canopy sizes and multi-spectral scanners can aid species identification. Other parameters such as trunk sizes and bark samples can only be provided by field contact. Investigations arecontinuing into use of ALS data for definition of Foliage Protected Coverage (FPC) statistics.

## PRODUCTS

A benefit and a disadvantage of ALS is the size of datasets. The technology can offer point spacings of less than one metre if required, but file handling can become a serious encumbrance. Over 313 million data points were captured during the trials; one client received over 21 million ASCII points which barely fitted on a 650Mb CDROM! Processes had to be found to present this data in a format manageable by the end user.

Products produced so far include:

- ASCII xyz files, divided into "ground" and "non-ground" files.
- Terrain contour plans, with the "non-ground" strikes shown as a small dot. These dots take on the appearance of vegetation stippling.
- Graphical profiles, showing the ground and non-ground surfaces.
- Spreadsheets containing "the tallest 3 trees falling within a 400m$^2$ cell", which provides the 75 tallest trees per hectare.
- Digital orthophotos in which the aerial photography is ortho-rectified on a digital elevation model defined by the tree crowns. Plotting the "non-ground" strikes on the orthophoto allows the forester to see which tree each specific laser strike refers to.
- Perspective views, which are particularly useful in urban environments to determine line of site and visual intrusion. Figure 6 shows a rendered view of a section the city of Brisbane formed from as ALS DEM.

With the quantity of data provided by ALS, it is clear that the data suppliers should liaise with data users to ensure that the spatial information is conveyed in a meaningful and readily useable format.

Data filtering algorithms are available to discard points which do not contribute to the model definition. Research of building and breakline definition is continuing however commercial utilisation of such a facility is some time away. (Hsiao & Wong 1999)

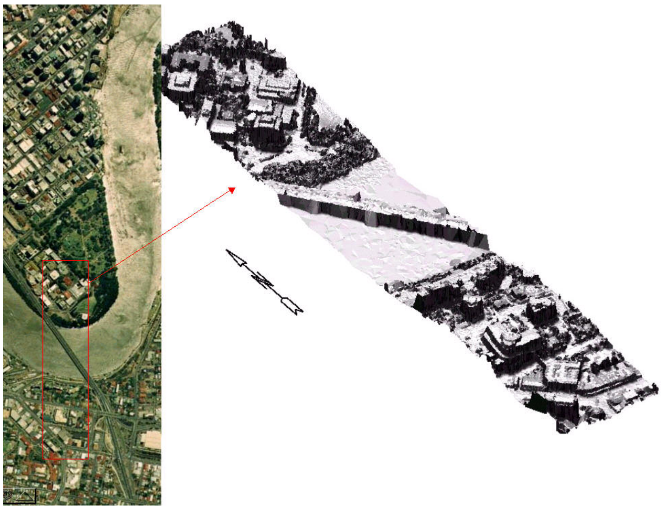

***Figure 6: City of Brisbane defined by airborne laser scan data***

# COMPARISON OF ALS WITH OTHER TECHNOLOGIES

In considering different methods of terrain modelling we need to consider the measure of quality of a terrain model.

Terrain models are created for a vast variety of applications, each having its own demands of the model. A design of a complex development with above and below ground services may require a combination of precision and accuracy such that any point interpolated from the model will be in error by <0.10m and a bias error of <0.05m. A model for slope analysis of agricultural land may require point errors of <0.5m and a systematic error of <2m.

In order to properly define the needs of a terrain model, and consequently define the quality achieved, we must consider:-

- the standard error of a single measured point
- the standard error of any derived point
- the mean error, or bias

The latter two are key model measures.

In comparing the available technologies, it is generally true to observe that:

- terrestrial surveying methods yield superior single measured point accuracy
- airborne surveying methods yield inferior single point measurement accuracy, but due to the ability to provide a denser pattern of measurements can surpass the terrestrial methods in accuracy of derived points
- airborne surveying methods are more prone to bias, using terrestrial surveying to identify and remove bias.

Because the density of measurements in any terrain model is infinitely variable it is not possible to directly compare model quality. Only single point errors are used in the following comparison table.

| **Technology** | **Typical Height Error Single Point (1σ)** | **Strengths** | **Weaknesses** | **Typical Point Density** | **Best Applications** |
|---|---|---|---|---|---|
| Total Station | ±0.03m (3D) | • accurate over limited areas<br>• low capital cost<br>• orthometric elevations<br>• in-field validation<br>• feature coding | • line of sight<br>• field coding errors<br>• data processing problems increase with area<br>• labour intensive<br>• access needed | None | • urban & industrial detail surveys<br>• smaller (≈5ha) rural surveys |
| GPS (RTK) | ±0.05m (3D) | • need for line of sight relaxed<br>• potential for vehicle mounting<br>• high productivity in kinematic mode<br>• feature coding | • ambiguity resolution required<br>• problems in forest and urban environments<br>• requires correction for geoid-ellipsoid slope<br>• separation of radio receivers limited by range and topography<br>• access needed | None | • vehicle-mounted, open terrain<br>• clear skies |
| Analytical Photog-rammetry | Variable according to photo scale/focal length ±0.1m 1:10,000 scale photography | • infinitely variable point accuracy from 0.03m→<br>• high productivity<br>• operator interpretation<br>• on-line feature coding<br>• ability to structure data at capture<br>• mature technology<br>• potential for post-photography control | • inability to measure through foliage<br>• high capital cost (at high end)<br>• labour intensive<br>• atmospheric & light conditions can cause accuracy loss<br>• weather constraints<br>• marginal future enhancement expected | • 20m separation for regular spot height grids, plus critical breaklines | • medium to large areas (100ha to 250,000ha)<br>• identification of breaklines important<br>• difficult site access |
| Digital (Soft) Photogram metry by Image Correlation) | Variable according to photo scale/focal length/terrain model type ±0.3m 1:10,000 scale photography | • semi-automatic aero-triangulation<br>• potential for batch processing<br>• digital OPM secondary product<br>• high point density<br>• significant enhancements expected<br>• potential for post-photography control | • automatic process offset by increased editing<br>• inability to distinguish foliage in model<br>• atmospheric & light conditions can cause accuracy loss<br>• weather constraints<br>• limited published accuracy tests | • 2 to 10m separation<br>• ordered grid | as above |
| Airborne Laser Scanning | ±0.15m | • penetration of forests<br>• day or night operation<br>• high point density<br>• reliable measurement of untextured surface<br>• ability to define multiple vertical layers<br>• significant enhancements expected | • high proportion of post-capture processing<br>• point data only<br>• model noise from foliage strikes<br>• base GPS receiver essential in all operations<br>• high capital cost | • 1m to 10m separation<br>• random point distribution | • medium to large areas with foliage<br>• multiple surface definition |

***Table 2: Comparison of Terrain Modelling Technologies***

It becomes increasingly clear that the trend for the future is the employment of two or more terrain modelling technologies and integration of their measurements.

## CONCLUSION

ALS is a valuable addition to the surveyors' kit of topographical measuring tools. Its major advantages are in the facility to penetrate forest cover and simultaneously define multiple surfaces. It can also measure texturlessterrain which resists photogrammetric image correlations.

Like most new technologies, ALS will not replace any of the established technologies. While ALS may well be considered a viable replacement for some applications now satisfied by photogrammetry, its major utilisation will most likely be in solving problems which are beyond any established technology – monitoring forestry resources, coastline and inter-tidal zones and power transmission lines.

As the surveying community comes to make use of ALS for just these particular applications, it will be making considerable contributions to the call of Agenda 21.

## REFERENCES

Vaughn, Charles R. et al (1996). "Progress in Georeferencing Airborne Laser Altimeter Measurements". Proc. Second International Airborne Remote Sensing Conference & Exhibition, San Fransisco, 24-27 June 1996.

Kost, W (1997). "Airborne Laser Scanning, A New Remote Sensing Method for Terrain Mapping". Proc. Fourteenth United Nations Regional Cartographic Conference for Asia and the Pacific, Bangkok, 3-7 February 1997.

Fraser, C., Jonas D., Turton, D. (1999). "Report on 1998 Airborne Laser Scanning Trials". Unpublished, available on request.

Chung S.H. (1999) "Airborne Laser Scanning for Elevation Mapping".GIM (reprint).

Lohr, U. (1996). "Surveying Single Objects with a Laser Scanner".GIM, September 1999.

Hsiao, H & Wong K.W. (1999) "Automatic Matching of Buildings & Corners". Photogrammetric Engineering & Remote Sensing, 65 (7) pp 803–810.