ANALYSIS OF GROUND TARGET DATA ON AIRBORNE LIDAR

Hongjoo Park[1], John Trinder*[1], Russell Turner[2] and Samsung Lim[1]
[1]School of Surveying and Spatial Information Systems, University of New South Wales, Sydney, Australia; Tel: +61-2-9385-4202; Email: hj.park@unsw.edu.au, j.trinder@unsw.edu.au, s.lim@unsw.edu.au
[2]Research Forester, Department of Primary Industries, NSW, Australia; Tel: +61-2-9872-0189;
Email: Russell.Turner@industry.nsw.gov.au

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ABSTRACT: The positional accuracy of airborne lidar data continues to improve. However, airborne lidar data is affected by a number of issues, such as laser sensor errors, footprint size and the relative displacements and differences in the orientations of each of the components on the platform. Even after each individual component is calibrated, positioning errors can remain in the lidar point data. Therefore, the positional accuracy of processed airborne lidar point data needs to be evaluated before it is used in practical applications. This paper investigates the potential of using Ground Control Point (GCP) targets for the refinement of airborne lidar coordinates. Test flights have been carried out with different flight parameters and target distributions and designs with point densities of approximately 2 points/m^2 (PRF of 80kHz), 5 points/m^2 (PRF of 240kHz), and 10 points/m^2 (PRF of 400kHz). The GCP targets were installed at two different locations within the test area and at two levels, consisting of three different materials, white plywood, green carpet and white styrofoam. The vertical and horizontal accuracy of the coordinates of the GCP targets derived from the three densities of lidar data were obtained by comparison with the positional data collected by field survey. A comparison of the performance of the three different GCP target materials is also discussed in this paper.

1. INTRODUCTION

Geo-referencing of lidar waveform data is affected by a number of issues, such as laser sensor errors and the relative displacements and differences in the orientations of each of the components on the lidar platform. To validate the accuracy of lidar geo-referenced data it is desirable to utilise targeted ground control points (GCPs) of known positional accuracy.. This paper will describe the design and placement of customised GCP targets in a forestry site and the assessment of lidar positional accuracies relative to these targets.

The study area is part of the State Forest at Sunny Corner, New South Wales (NSW), situated about 150km west of Sydney and managed by Forests NSW[1]. The study site covers an area of about 140 hectares. Figure 1 shows the 2km × 0.7km study area indicated by the blue box while the red lines display the three different airplane trajectories over the area. This study area was selected because there are variable tree canopy heights with several different age classes of Monterey pine trees (botanical name: *Pinus radiata*). Four strata classes were selected in the test area where trees were planted in 2008, 2005, 1994 and 1969 (Park *et al*. 2011). Within each strata 30 trees were selected and top height measured by total station (TS), terrestrial laser scanner (TLS) and airborne lidar.

Each GCP was located using Leica GPS-1200 receivers and measured using static mode GPS with a 1s sampling rate for sessions of more than 60 minutes. The Bathurst and Lithgow reference stations were less than 25km from the test area, so either station could be used to process the baseline between the reference station and each GCP. The precision of GPS positioning using post-processed static observations over a baseline length of less than 25km is expected to be no worse than 2cm in horizontal coordinates and 5cm in vertical (height) coordinates (Geoscience Australia, 2005). The coordinates of the GCPs were determined by post-processing the GPS observations using the Leica Geo Office (LGO) commercial software. The coordinate system of this experiment was the Map Grid of Australia (MGA) in Zone 55.

1.1 GCP Target Design

Since the GCP targets were required to assess the accuracy of the three lidar data flights over the test area, one group of GCP targets was placed at the centre of the test area and the other group towards the north-east edge of the

[1] Forests NSW (FNSW) is a public trading enterprise within NSW Department of Primary Industries. FNSW works to protect biodiversity in state forest, achieve other environmental benefits and provide community amenities – all within the framework of running a profitable business for the people in the state of NSW, Australia.

test area. At each GCP target location there were three pairs of targets made of different materials. For each pair made with the same material, one was placed at ground level and the other 1m above the ground. This was done to determine whether there is any accuracy discrepancy between the ground surface and above ground objects.

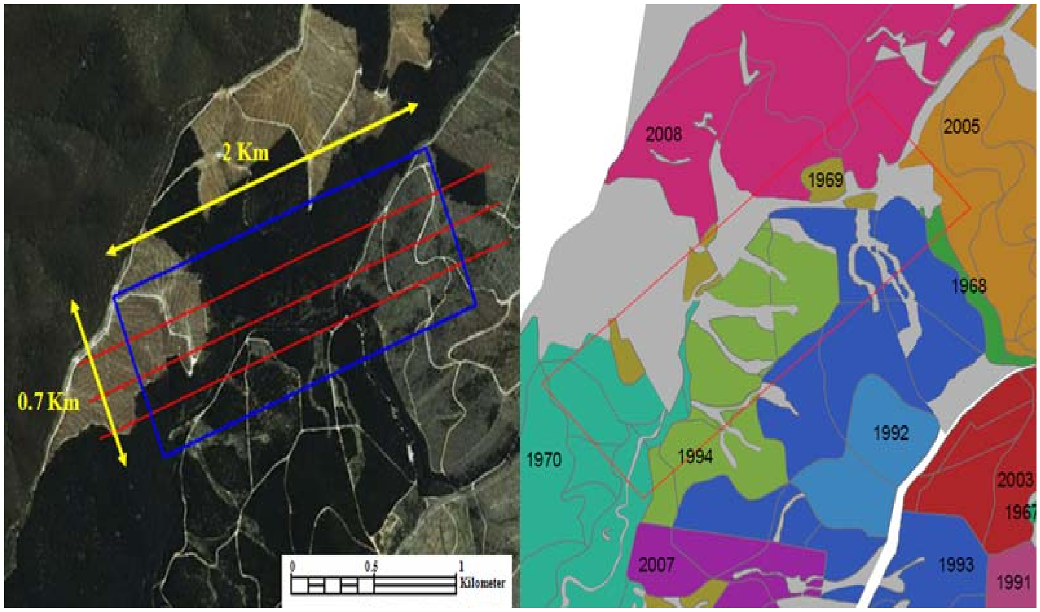

Figure 1. Study area at Sunny Corner State-Forest in NSW, Australia

The GCP targets were designed with dimensions of 1.2m x 1.2m. These dimensions were selected to ensure that at least two lidar points would occur on each target under the assumption that the lidar point sampling density would be at least 2.0 points/m^2. Targets made of various materials were used to compare the intensity values of lidar points obtained from different target materials.

Three factors were considered when choosing target materials (Csanyi and Toth, 2005, Graham, 2006);

- Colour – dark colour materials absorb the lidar signal and will not be easily detected, since sufficient signal must be returned to the sensor for the target to be visible.
- Roughness –roughness in the target material will ensure that some of the incident laser beam will be reflected in a diffuse manner and hence provide a better return to the laser sensor. Extremely smooth target materials, such as oil and water, should be avoided as they act as specular reflectors and hence little or no return signal will reach the laser sensor.
- Man-made high-reflection surfaces – highly reflective materials, such as reflective foils, may return an unusually strong signal which would saturate the receiver and reduce the precision of the measurement. In extreme cases such materials could reflect the full beam back into the laser emitter, causing damage to the laser sensor.

Three materials; white painted plywood, green carpet on plywood, and white Styrofoam were used as GCP targets as follows:

- White painted plywood (Ground height) - A
- White painted plywood (Height = 1m above ground) - B
- Green colour, carpet on plywood board (Ground height) - C
- Green colour, carpet on plywood board (Height = 1m above ground) - D
- White colour, Styrofoam on plywood board (Ground height) - E
- White colour, Styrofoam on plywood board (Height = 1m above ground) – F

2. Collection of Full Waveform Airborne Lidar Data

The full waveform lidar data was collected after the placement of the targets by a Trimble's Harrier 68i system, installed on a Beechcraft Bonanza A36 airplane. The flight parameters and laser sensor specifications are listed in Table 1. The GPS reference station was set up at Bathurst Airport, which is approximately 25km from a primary data collection area. The lidar data was collected at 3 different Pulse Repetition Frequencies (PRFs) (80kHz – 2.0 points/m^2, 240kHz – 5.0 points/m^2 and 400kHz – 10.0 points/m^2), each pulse rate being taken on 3 separate passes over the area as shown in Figure 1. For the 400m flying height, the footprint size on the ground was approximately 0.2m in diameter.

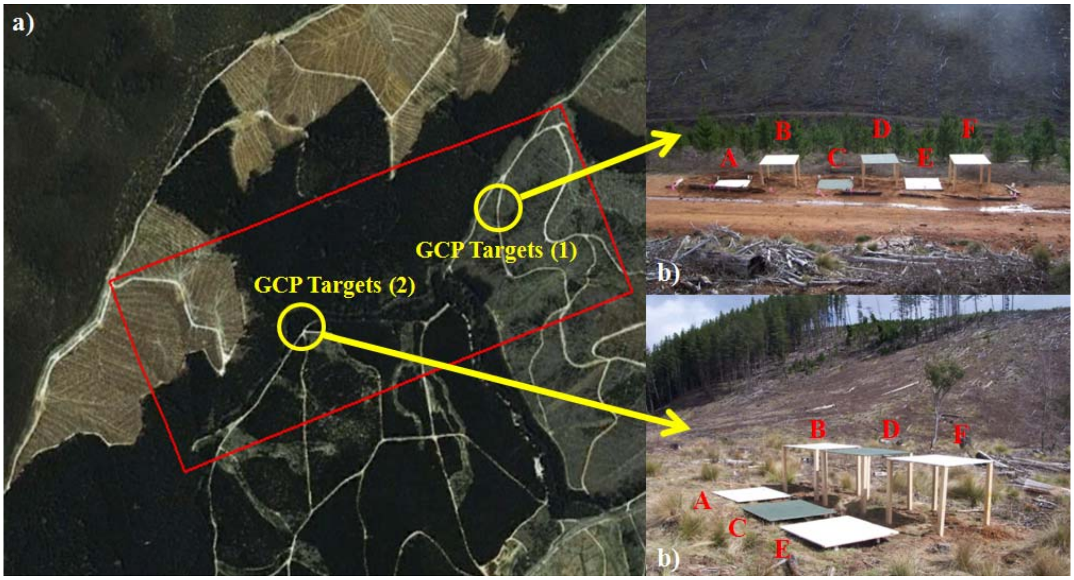

Figure 2. Installed the GCP targets in study area

Table 1 Data acquisition parameters for 11th September, 2010 flight mission

Aircraft	Beechcraft Bonanza A36
Strip width	331 m
Flight height	400 m
Run spacing	215 m
Flight speed	60 m/second
Airplane trajectory	3 lines
Total length (each overpass)	7 km
Lidar System	
Company / Lidar system model	Trimble / Harrier 68i
Laser Sensor Specifications	
Laser scanner	RIEGL LMS-Q680i
Laser wavelength	Near infrared
Beam deflection / Scan pattern	Rotating polygon mirror / Parallel scan lines
Measurement range, Min	30 m
Measurement range, Max (natural target (reflectivity) ρ≥20%)	2000 m (80 kHz), 1350 m (200 kHz), 1150 m (300 kHz), 1000 m (400 kHz)
Scan angle	Up to ± 30.0 degrees
Scan speed	10-200 lines / second
Angle measurement resolution	0.001°
Laser pulse rate (pulse repetition frequency)	Up to 400,000 Hz PRF
Laser wavelength / Intensity capture	1,550 nm / 16 bit per return amplitude
Spot diameter	50 cm @ 1,000 m
Pulse resolution	0.1m (wave form mode) pulse width resolution
Point accuracy (horizontal / vertical)	19 m / 7 cm (1 sigma)

3. TS Field Surveying of Tree Heights

A Leica TCRP 1203 Total Station (TS) was set up over the GCPs and canopy heights of 30 sample trees of 4 different ages of the trees planted in 2008, 2005, 1994 and 1969 were measured in the reflector-less mode. Field TLS surveys were also performed to obtain data for a number of pine trees located within the study area in order to compare tree canopy heights derive by TLS, with those derived by TS and airborne lidar. The expected precision of the TLS position coordinates is a few cm. The Root Mean Square Errors (RMSE) of the geo-referencing of all TLS data were 0.015m horizontally and 0.040m vertically (Park *et al*. 2011). After geo-referencing the individual tree canopy heights are determined by finding the highest point in the data. Examples of the sample trees heights for the 2 ages of the trees planted in 1994 and 1969 are show in Figure 3. The extraction of individual tree canopy height is based on an algorithm to find the maximum height in the canopy data of each tree, which is the peak vertical point in a defined sample area. This defined area is manually selected as a search window outlining the sample tree. The size of this box is dependent on the tree crown size but a 7m by 7m search window was normally sufficient for large trees.

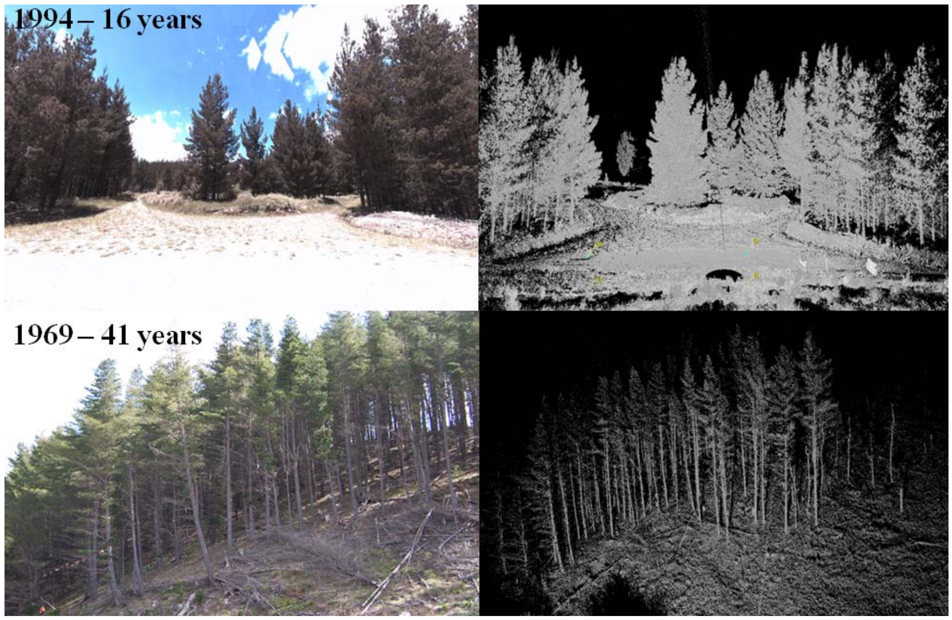

Figure 3. Photo of trees vs processed TLS data (top: 16 year old trees, bottom: 41 year old trees)

4. ASSESSMENT OF ACCURACY OF TARGETS

The horizontal position of each GCP target was determined by taking the mean of the horizontal positions of the lidar points falling on the target. The errors in the estimation of the horizontal positions of the targets and their RMSE were obtained by comparing the horizontal positions of the GCP derived from the aerial lidar data with the coordinates of the targets derived from the field survey. Table 2 summarizes the horizontal positional errors and RMSE of all targets for the different lidar point densities, where it is clear that the target positions are more accurate for the sampling density 10.0points/m^2 than can be achieved for lower lidar sampling densities, because of the higher number of incident points on the target.

The errors and accuracies of the elevations of the targets derived by the aerial lidar were also compared with the field survey results as given in Table 3. The results are summarized as follows:

- The mean elevation errors for the ground level targets were generally less than 0.05m and the RMSE less than 0.02m; surprisingly the errors for the 10points/m^2 were larger than for the less dense sampling
- The mean elevation errors for the targets 1m above ground level were generally less than 0.03m and the RMSE also less than 0.02m. The large error for the 10points/m^2 was due to suspected disturbance of the target before the flight and hence has been rejected. Therefore the ground level and 1m high targets gave statistically similar vertical accuracies for both test areas.
- The mean elevation error in the GCP target area (2) was found to be higher than that of target area (1) and is likely to be due to lidar calibration error. This error could be attributed to the different scan angle for the two target areas. The scan angle for target area (1) is ~7°, while the angle for target area (2) is ~ -3°.
- There was no apparent different in accuracies of elevations for the different target types.

4.1 Analysis of Suitability of Target Materials

An assessment of the intensity of the lidar points on each target, summarised in Table 4, reveals that test materials A, B (white painted plywood) and E, F (white Styrofoam) exhibit similar intensity values and are much higher than for material C, D (green carpet). From this it is determined that hard, white coloured targets are preferable for lidar ground targets. It can also be seen that as the lidar PRF increases, the intensity values decrease, because a higher PRF results in a lower energy of the emitted laser pulse and as a consequence the received return signal power decreases (Csanyi and Toth, 2006).

Table 2 The horizontal positional errors and RMSE of the lidar data compared with field data for all GCP targets

Lidar data density	Horizontal positions error in GCP target area (1)			
	Easting		Northing	
	Mean (m)	RMSE (m)	Mean (m)	RMSE (m)
Lidar data (2points/m^2)	0.039	0.088	-0.004	0.159
Lidar data (5points/m^2)	-0.008	0.050	-0.007	0.037
Lidar data (10points/m^2)	0.024	0.040	0.007	0.046
Lidar data density	Horizontal positions error in GCP target area (2)			
	Easting		Northing	
	Mean (m)	RMSE (m)	Mean (m)	RMSE (m)
Lidar data (2points/m^2)	0.079	0.094	0.069	0.095
Lidar data (5points/m^2)	0.005	0.043	0.049	0.078
Lidar data (10points/m^2)	0.009	0.044	-0.005	0.029

Table 3 Elevation errors and RMSE for lidar point data compared with field survey (GCP target (1))

GCP Targets (Ground level)				
Data density		Targets materials		
		A	C	E
Lidar data height (2points/m^2)	Mean error (m)	-0.006	-0.024	-0.004
	RMSE (m)	0.005	0.017	0.008
Lidar data height (5points/m^2)	Mean error (m)	-0.033	-0.027	-0.019
	RMSE (m)	0.013	0.006	0.019
Lidar data height (10 points/m^2)	Mean error (m)	-0.042	-0.034	-0.047
	RMSE (m)	0.007	0.008	0.011
GCP Targets (1m above ground level)				
Data density		Targets materials		
		B	D	F
Lidar data height (2 points/m^2)	Mean error (m)	-0.004	-0.005	0.020
	RMSE (m)	0.008	0.008	0.017
Lidar data height (5 points/m^2)	Mean error (m)	-0.029	-0.030	-0.012
	RMSE (m)	0.010	0.008	0.014
Lidar data height (10 points/m^2)	Mean error (m)	-0.233	-0.154	-0.082
	RMSE (m)	0.032	0.031	0.031

Table 4 Intensity values of lidar point data on GCP targets

GCP Targets (1)						
Data density	Average intensity value of GCP targets					
	A	B	C	D	E	F
Lidar data (2.0 points/m^2 – 80 kHz)	3236	3101	897	647	3468	2938
Lidar data (5.0 points/m^2 – 240 kHz)	875	959	165	141	1067	1398
Lidar data (10.0 points/m^2 – 400 kHz)	599	548	115	99	628	623
GCP Targets (2)						
Data density	Average intensity value of GCP targets					
	A	B	C	D	E	F
Lidar data (2.0 points/m^2 – 80 kHz)	3726	3292	112	122	3498	4676
Lidar data (5.0 points/m^2 – 240 kHz)	1040	1134	30	31	1212	1510
Lidar data (10.0 points/m^2 – 400 kHz)	636	618	24	19	674	812

Target types: A and B – white pained plywood; C and D – green carpet; E and F- Styrofoam.

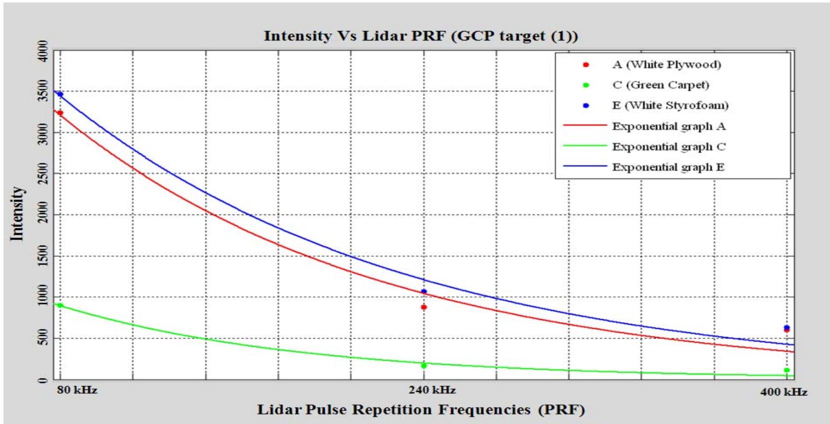

Figure 4. Intensity values for three densities of lidar PRF for the GCP targets. An approximate exponential curve has been fitted to the points.

The reason for this is that the laser employed is average-power limited. The average power produced by the laser is indifferent to the PRF, i.e. there is a limit to the available energy for the pulses; hence the higher the PRF the lower the available energy to each pulse (Pfennigbauer and Ullrich, 2011). Figure 4 shows the approximate relationship between the intensity and the lidar PRF for the three different materials. Each data point is an average of the lidar point intensity values falling on the target. The effect of decreasing return intensity with increasing lidar PRF could have implications for future studies investigating the use of intensity parameters for vegetation classification. It may be possible that certain sampling intensities may be optimum for distinguishing different vegetation.

5. CONCLUSION

The paper has described the horizontal and vertical positional accuracies of ground targets derived from the full waveform aerial lidar data over a forestry test area. The horizontal accuracies of the target locations increased as the PRF increased, from about 9cm for 2points/m^2 to 4cm for 10points/m^2 while the positional errors varied but tended to be of the order of 0.05m. The vertical accuracies were of the order of 0.02m and varied little for the different PRFs. Both horizontal and vertical accuracies (in open ground) were found to be higher than the manufacturer's specifications of accuracies, which is a significant result. Three different material types for GCP targets were assessed and it was found that white coloured targets produce higher intensity values than darker targets, thus providing for easier identification of targets in the data analysis stage. However, the type of target material had no significant influence on the positional or elevation accuracies. It was also found that intensity of the return pulses decreased with increasing PRF, due to the limited average-power available to the laser.

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