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CORSnet-NSW and Airborne LiDAR: A Match Made in Heaven

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CORSnet NEW SOUTH WALES

NSW GOVERNMENT Land & Property Information

INTRODUCTION

CORSnet-NSW is a rapidly growing network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use [1,2].

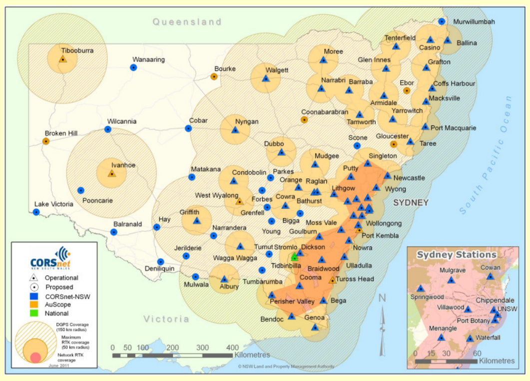

Figure 1: Current Status of CORSnet-NSW (June 2011).

CORSnet-NSW supports a wide range of GNSS applications in areas such as surveying, agriculture, mining and construction, and provides a solid platform for research and innovation involving satellite positioning technology. The network is built, owned and operated by Land and Property Information (LPI), a division of the NSW Department of Finance and Services. Currently consisting of about 65 permanent stations tracking multiple satellite constellations, CORSnet-NSW will expand to over 120 stations within the next two years (Figure 1).

Airborne LiDAR (Light Detection and Ranging) surveys produce very accurate, high-resolution terrain models which are used for many surveying and engineering applications including critical environmental analysis functions such as coastal vulnerability, flood inundation mapping, assessment of the impact of rising sea levels and hydrological modelling for water resource management. The key to producing high-quality elevation products is very precise geolocation and orientation of the LiDAR instrument during the survey, obtained with a combination of on-board GNSS and inertial navigation system (INS) sensors (Figure 2). If the LiDAR survey is to achieve the now expected high level of vertical accuracy (±15 cm, 1 sigma), then the position of the GNSS/INS-derived aircraft trajectory for each laser swath must be determined with a relative precision in the order of just a few centimetres.

The usual practice to achieve this is to deploy temporary GNSS receivers at sites within the survey area, utilising differential GNSS techniques to obtain a precise aircraft trajectory. For reliable ambiguity resolution the aircraft generally needs to be no further than 30 – 50 km from these temporary or permanent reference stations at all times. Therefore, if the area surveyed is large, this requires a significant logistical overhead in operating receivers at multiple sites during a flight mission.

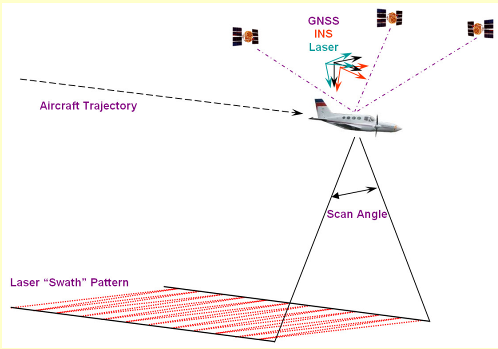

Figure 2: Airborne LiDAR "reference frame".

The GNSS positions are then blended with high-frequency measurements taken by the onboard INS to produce the final trajectory and reference orientations of the LiDAR instrument.

WIDE-AREA DIFFERENTIAL GNSS

Ideally, permanent GNSS reference stations would be available for precise airborne positioning across the full extent of New South Wales. The reality is that although CORSnet-NSW will provide substantial state-wide coverage, existing "off-the-shelf" software currently used to process such dynamic GNSS observations requires a density of CORS sites that is neither practical nor economically viable to establish. The solution is to combine the positioning infrastructure provided by CORSnet-NSW with a wide-area GNSS technique which removes the cost, logistical and computational complications of deploying temporary reference stations within the survey area.

The **wide-area positioning software "IT"** (Interferometric Translocation) [3] developed by one of us (Colombo) is shown to achieve comparable precision and accuracy to that of short-baseline solutions, even with baseline lengths of several hundreds of kilometres. Figure 3 shows a comparison between aircraft trajectories computed with IT using data from a temporary GNSS receiver within the survey extent and a CORSnet-NSW reference station some 600 km distant.

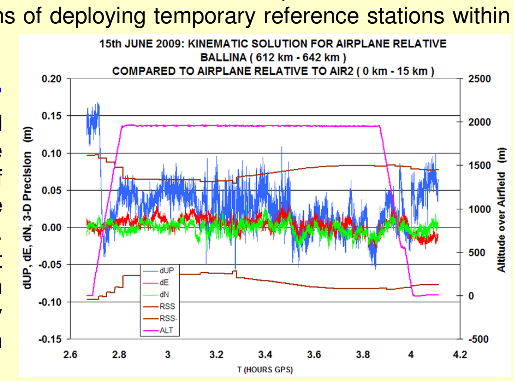

Figure 3: Trajectory comparison (E,N & Up differences).

In 2009, as part of LPI's LiDAR test and development program, the opportunity was taken to use flight data and associated ground control from a bore-sight calibration survey at Bathurst airport to compare LiDAR point data derived from trajectories computed with "IT" using various combinations of distant CORSnet-NSW reference stations [4]. Figure 4 shows the location of the survey site and local GNSS reference station AIR2, along with the CORSnet-NSW sites selected for wide-area computations. Rather than simply comparing aircraft trajectories, this study aimed to determine what effect the use of wide-area GNSS positioning has on the actual LiDAR point data and associated elevation surfaces.

Figure 4: Bathurst (AIR2) test site location.

In order to quantify the differences between LiDAR data generated from the locally-computed trajectory (assumed to be "truth") with each wide-area derived trajectory, the following **test methodology** was applied:

1. Comparison of trajectories.
2. Relative point comparison, i.e. comparing the positions for a sample of LiDAR ground points.
3. Digital Elevation Model (DEM) comparison , i.e. differencing raster surfaces to find the effect over a LiDAR run.
4. Absolute LiDAR ground control comparison, i.e. comparing the LiDAR-derived surface from various trajectories to the surveyed ground control.

TEST RESULTS

The **trajectory comparison** in Figure 5 shows the vertical component of five wide-area derived trajectories, using various combinations of CORSnet-NSW sites, compared to the locally derived trajectory (using AIR2). The results show a remarkably consistent comparison with the locally derived solution. The spikes visible in the DBBO/WGGA/NEWC (yellow) solution are attributed to small data glitches at DBBO. Unfortunately, LiDAR observations were not being collected at those instances, therefore the effect on ground data could not be fully assessed.

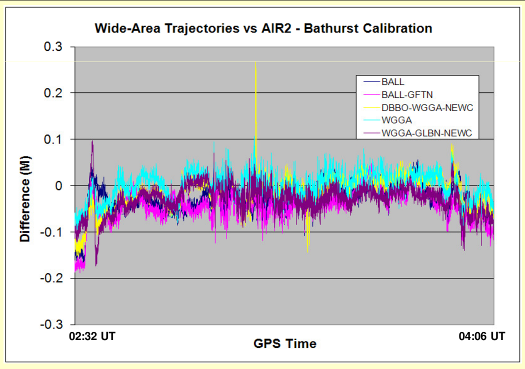

Figure 5: Trajectory comparison using CORSnet-NSW sites.

Table 1: Displacement vectors of LiDAR points in metres.

CORSnet-NSW sites		Min.	Max.	Average
BALL (626 km baseline)	East	-0.013	-0.005	-0.009
	North	-0.034	0.012	-0.012
	Vertical	**-0.031**	**-0.003**	**-0.020**
BALL/GFTN (average 570 km baseline)	East	-0.009	0.002	-0.004
	North	-0.036	0.007	-0.015
	Vertical	**-0.048**	**-0.014**	**-0.037**
DBBO/WGGA/NEWC (average 220 km baseline)	East	-0.035	-0.026	-0.031
	North	-0.031	-0.002	-0.016
	Vertical	**-0.020**	**0.017**	**-0.008**
WGGA (280 km baseline)	East	-0.024	-0.009	-0.018
	North	-0.028	0.000	-0.014
	Vertical	**-0.027**	**0.015**	**-0.016**
WGGA/GLBN/NEWC (average 210 km baseline)	East	-0.006	0.004	-0.002
	North	-0.029	0.003	-0.015
	Vertical	**-0.020**	**0.017**	**-0.009**

Relative point comparisons were performed in 25 sample areas of 100 m² in size (consisting of 1700 points in total). Table 1 summarises the displacement vectors between individual LiDAR points derived from five wide-area solutions compared with those from the locally derived solution utilising AIR2. The results clearly show that the height values agree to within a few centimetres, even over baselines exceeding 600 km.

In order to investigate how the **DEM surfaces** derived from each trajectory compare across the entire data swath, raster surfaces were created from the LiDAR point data. Each surface was then subtracted from the local solution to create a difference surface. The result shown in Figure 6 was typical of the cyclical effect evident for all solutions with a magnitude in the order of 2-3 cm, which has an expected correlation with the related trajectories as shown in Figure 7.

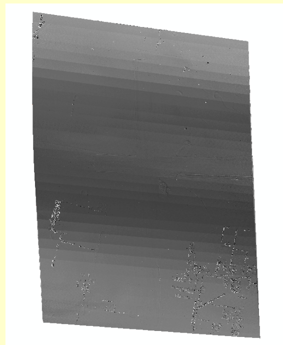

Figure 6: DEM surface difference.

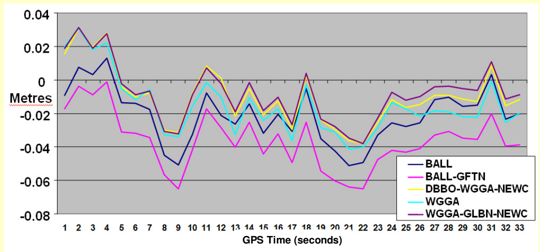

Figure 7: Trajectory segments for DEM generation.

Table 2: Comparison of LiDAR surfaces with surveyed ground control (meters).

TRAJECTORY	Mean	Min	Max	RMSE
GrafNavAIR2	0.000	-0.082	0.089	0.033
AIR2	0.000	-0.075	0.100	0.032
BALL	0.000	-0.075	0.100	0.032
BALL/GFTN	0.000	-0.074	0.102	0.032
DBBO/WGGA/NEWC	0.000	-0.072	0.098	0.032
WAGG	0.000	-0.072	0.098	0.032
WAGG/GLBN/NEWC	0.000	-0.074	0.098	0.032

Finally, the LiDAR surfaces derived from trajectories using all wide-area differential GNSS solutions, the local (AIR2) solution as well as a "GrafNav" solution (popular proprietary software) were compared to **surveyed ground control**. Following usual practice for LiDAR operations, the data was adjusted such that the mean fit is zero. Table 2 clearly shows that all solutions are virtually identical with an RMSE of 32 mm.

CONCLUSIONS

CORSnet-NSW and airborne LiDAR are a match made in heaven. The results presented here show that the use of a precise wide-area positioning technique for airborne trajectory solutions provides both relative and absolute accuracies similar to those derived from using a local GNSS reference station. In particular, it has been demonstrated that irrespective of which reference sites are used, and once calibration and antenna modelling issues are addressed, the absolute comparison with ground control is well within the required accuracy for LiDAR operations.

It is clear that a GNSS CORS network such as CORSnet-NSW is capable of providing data for the computation of an accurate sensor trajectory for airborne LiDAR surveys. This potentially negates the need to establish temporary GNSS reference stations close to the survey area – an exercise which not only requires significant resources but also reduces the operational flexibility of the aircraft in regards to weather conditions and priority response applications.

The challenge for the use of this technique in an operational environment is to define and maintain a precise reference frame for all GNSS CORS network sites, including the use of a stable ellipsoidal height datum with compatible geoid modelling in order to provide local orthometric elevation data. Also, the knowledge base required for the computation of wide-area GNSS solutions is significant and requires an understanding of geodesy, GNSS positioning, absolute antenna modelling, application of precise ephemerides and derivation of the other parameters inherent to successful ambiguity resolution over such long distances.

Regardless of the GNSS processing methods, a LiDAR survey will always require independent ground surveys for the collection of vertical check points. These check points ensure that the accuracy meets specifications, and provide the means to define any transformations necessary to fit LiDAR data with the local height datum.

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