A COMPARISON OF POSITIONING ACCURACY FOR AIRBORNE LIDAR DATA SOLVED BY DGPS AND PPP

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Abstract:
The positioning accuracy of airborne LiDAR point clouds is mainly originated from GPS positioning. In general, DGPS method is used in Taiwan for solving the position of GPS rover on the air-plane with a ground base station within 20 km. However, part of the high mountains in Taiwan is inaccessible, where suitable site for installing ground reference stations is almost impossible. It is important to know the potential of applying Precise Point Positioning(PPP). PPP by using IGS GPS satellite precise ephemeris and clock anywhere in the world can achieve real-time or post processing for high-precision positioning. In this study, a test is carried out by using both conventional DGPS and PPP methods for a block of 6 selected flight strips of LiDAR scans. Results of LAS data generated by both methods are compared by the TIMESTAMP of point clouds for both before and after strip adjustment. In addition, results of adjustment of strips combined from both DGPS and PPP are compared with those of all strips of DGPS and, thus, to understand the possibility of using PPP instead of DGPS for the area not accessible for installing continuous GPS stations. DSMs interpolated from all points of DGPS computation are compared with those of PPP. It is concluded that though there is a datum difference between DGPS and PPP, strips of point clouds generated by PPP can be effectively merged into strip adjustment combining both strips of point clouds by DGPS and PPP.

1. INTRODUCTION

Typhoon Morakot hit Southern Taiwan on 8-9 August 2009. The tropical cyclone caused the worst geohazards in a century including landslides, mudflows, and flooding. A national geohazard mapping program employing airborne LiDAR and digital photography is thus initiated by Central Geological Survey Taiwan. As shown in Figure 1, the whole territory will be surveyed and covered with very detailed DEM and DSM of 1m grid and digital aerial photograph of 50 cm grid, as well as an inventory of the geological disastrous features with the acquired LiDAR data and images (Liu & Fei, 2011). Until the end of August 2012, 10 survey blocks denoted as 1-1 ~ 3-3 are almost completed with LiDAR DEMs which fulfill the requirements of hydro-flattening (Wu et al., 2012).

Taiwan is located on the suture zone of active tectonic plates between the Philippine Sea Plate and Eurasian Plate. Therefore, the rocks are highly fractured and the terrain is with extremely high relief. More than two thirds of the land are covered by hills and mountains. As shown in Figure 2, more than 30% of the land are with a heights of more than 1500 m above sea level where the reliefs between valley bottoms and ridges are high, so that LiDAR operation becomes very difficult. In addition, the area is in tropical and sub-tropical climate. Clouds and bad weather conditions form additional challenges for the airborne survey. Re-flights to supplement gaps due to clouds and narrow strips on mountain tops become very critical (Hsu et al., 2012). One of the challenges is the installation and maintenance of GPS ground control stations in the in-accessible high mountain tops during air sorties and the retrieval of the received GPS datasets in due time for post processing of the LiDAR data.

After the raw laser returns are acquired by air missions, the accurate geodetic coordinates of the point cloud will be converted by using the timestamp of the laser ranging data and the trajectory obtained by GPS and IMU. GPS is used for positioning of the trajectory in the air. The attitudes of the platform are sampled with IMU with a higher rate than the GPS to obtain a better accuracy of the trajectory. Therefore, GPS is critical for maintaining the accuracy of the LiDAR point clouds.

Currently, DGPS (Differential GPS) approach is used to be adopted for airborne LiDAR survey. It is known that many error sources such as GPS satellite orbits and time delay can be substantially reduced by differential processes. Usually, a kinematic positioning accuracy of DGPS can be better than 0.2 m (Seeber, 1993; Parkinson &

Enge, 1996). In comparison, PPP (Precise Point Positioning) approach combines results from a single receiver with location and time information from satellites and clocks. Therefore, the advantage is that PPP approach can do without a remote ground control GPS station. It is also proved that a kinematic positioning accuracy of PPP can be better than 0.2 m (Cove & Santos, 2004; Lin & Tzeng, 2006).

The accuracy of GPS positioning is a critical factor for the data quality of airborne LiDAR. In current practice, a ground GPS station within a distance of 20 km to the GPS on airplane is used for DGPS computation to obtain an accurate trajectory. It has been a great challenge to accomplish such a requirement in the high mountains of Taiwan. If PPP approach can achieve comparable accuracy, this would be a good substitute in case ground stations are not available. To understand the possibility of using PPP instead of DGPS for the area not accessible for installing continuous GPS stations or for some survey strips of which ground GPS stations are not available or with bad quality of data, results of adjustment of strips combined from both DGPS and PPP are compared with those of all strips of DGPS in this paper.

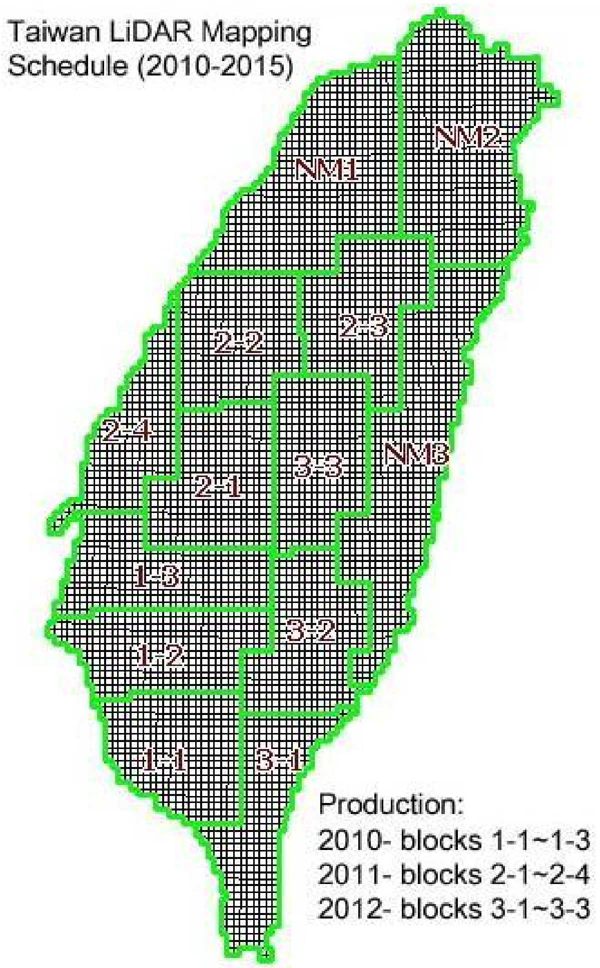


Figure. 1: LiDAR survey plan in 2010-2012 of Taiwan for Morakot disaster area is denoted with 2 numerical numbers. The area is sub-divided into 10 survey blocks for three survey teams to finish in three years. NM1~3 are extended areas in a subsequent project from 2013-2015. Each map unit is a 1/5000 national map frame with a size around 2.5x2.8 km^2.

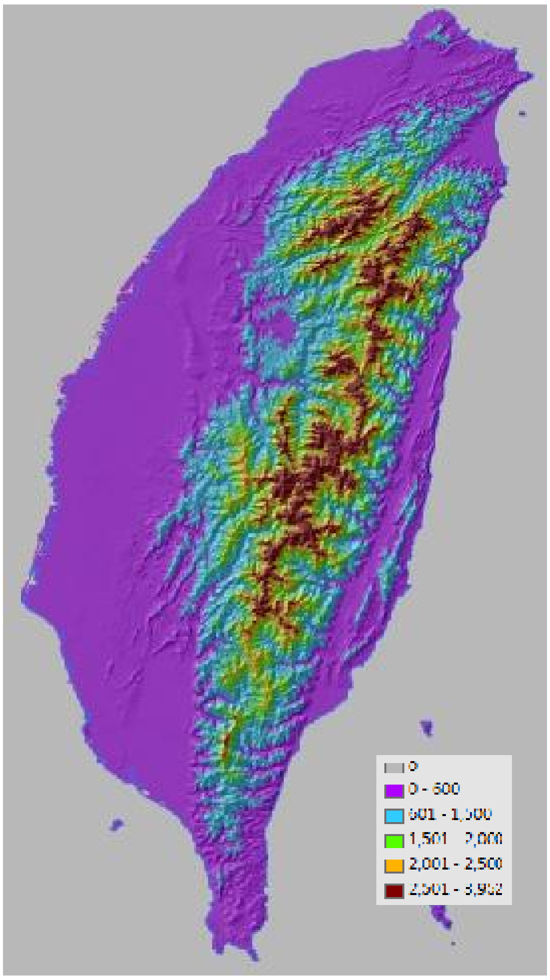


Figure. 2: The high relief of Taiwan. Two thirds of the land are covered by hills and mountains with more than 30% having a height more than 1500 m above sea level.

2. METHODS

2-1 Research materials

Six strips of LAS data obtained by Leica ALS60 are used in this study. As shown in Figures 3 and 4, they are denoted as strips #5, #6, #7, #8, #9 and #10, respectively. Strips #9 and #10 were acquired on 27 December 2011; strips #5 and #6 on 19 January 2012; #7 on 28 January 2012; and #8 on 5 March 2012. Because the time of acquisition is dispersed in different session of a week, the timestamps of laser points are unique for each point. All the strips are closely spaced from south to north and form a survey sub-block. The length of each strip is 26 km and the widths of strips ranges from circa 1600 m to 1700 m.

Table 1 shows the flight parameters applied in this survey. Terrain heights above mean sea level of this area ranges from 2896 m to 3353 m (Figure 4). Terrain units include build-up area, lakes, valleys, ridges and dense forest. Flight heights above ground level ranges from around 2100 m to 2500 m. The FOV settings include 30 and 38 degrees. Commercial package of TerraScan was used to handle the LAS datasets (Soininen, 2010) (Figure 5).

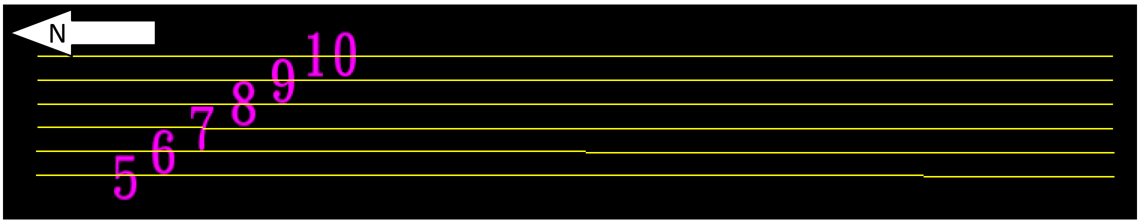


Figure 3: Plan of Flight lines

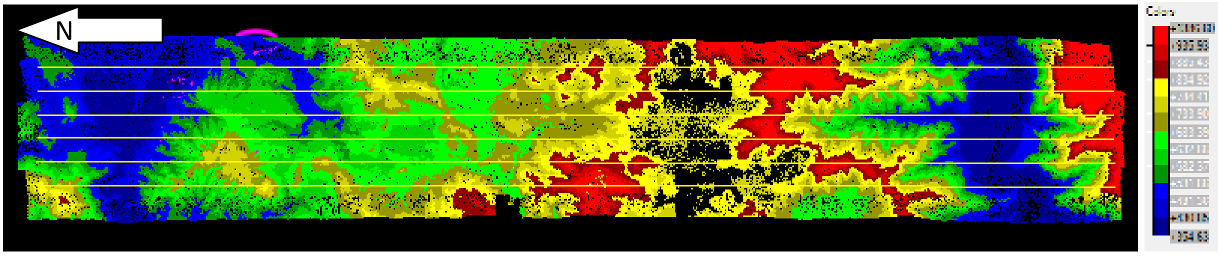


Figure 4: Topography of the study area

Table 1: Parameters used for LiDAR Data Acquisition

Flight Line Label	Alt MSL WGS84 [m]	FOV [deg]	Mean ref Height [m]	Swath Width [m]	Used Laser Pulse Rate[Hz]	Used Scan Rate[Hz]	Target Speed[kts]
5	2,896	38	687.5	1,754	96,100	30.8	100
6	2,896	38	691	1,749	96,100	30.8	100
7	2,896	38	670.5	1,744	96,100	30.8	100
8	3,353	30	793.5	1,599	82,700	29.1	100
9	3,353	30	852	1,597	82,700	29.1	100
10	3,353	30	853	1,596	82,700	29.1	100

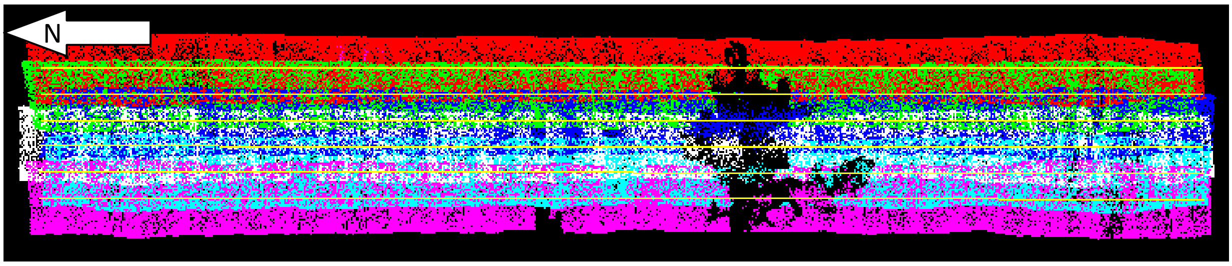


Figure 5: Resultant flight strips of LAS data

2-2 Method

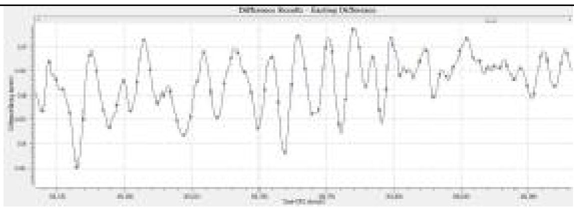
Two identical datasets of raw scanning data are used for entry into the DGPS approach and PPP approach, respectively for obtaining trajectories. First of all, the purpose is to know the differences in trajectories obtained by DGPS and PPP, respectively. Basically, DGPS and PPP are in different datum. Subsequently, two sets of RawLAS point clouds are generated separately by these two trajectories. Las2txt of LAStools (2012) is used to export corresponding points of ENZ coordinates with identical Timestamp. The differences in 3 dimensions of coordinates can thus be compared. Finally, 2 different approaches of strip adjustment are employed (Soininen, 2004), including (1) all strips of point clouds are solved with DGPS, and (2) Strips of #5, #6, #9, and #10 are solved with DGPS, and strips of #7 and #8 are solved with PPP. This is to simulate the situation that DGPS data are not available for these 2 flight strips.

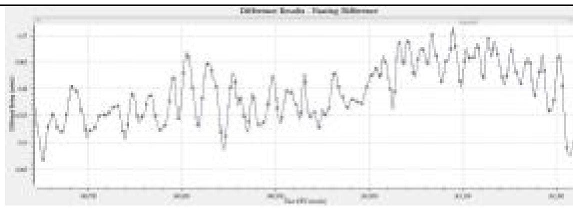
3. RESULTS

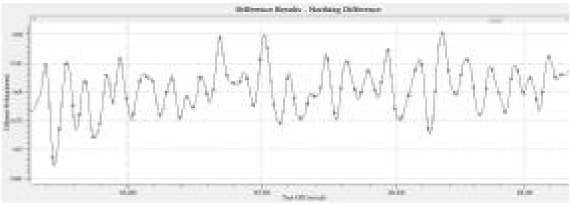
Four different results of DGPS and PPP are compared, namely (1) the trajectories, (2) the RawLAS, (3) the LAS after strip adjustment, and (4) the LAS of combined adjustment of DGPS and PPP with that of DGPS-only.

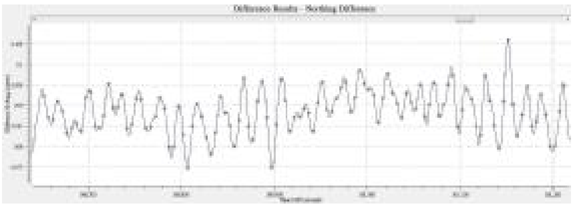
3-1 Comparison of the trajectories by DGPS and PPP

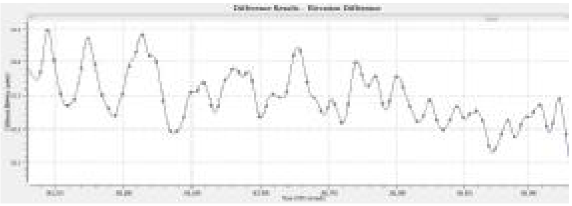
If DGPS trajectory is used as a reference for comparison, the fluctuation of deviation of PPP trajectory in E, N, and Z directions can be shown as Figure 6. In horizontal direction of dE and dN, the differences ranges from 0.004 m to 0.106 m. In vertical direction, the differences of dZ ranges from 0.040 m to 0.215 m. In general, the difference is in the order of 0.1 m. In other words, a substantial difference exists.

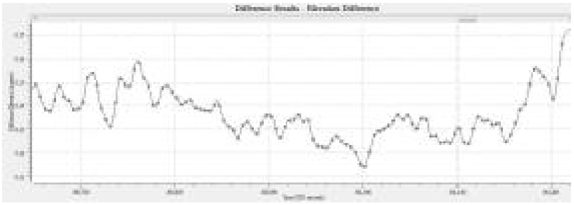

Trip 5: dE 0.045~0.075 m

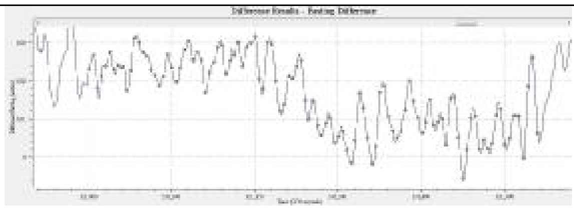

Trip 6: dE 0.045~0.073 m

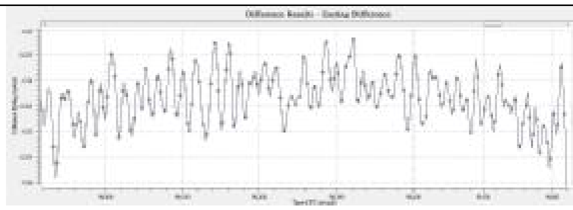

Trip 5: dN 0.065~0.090 m

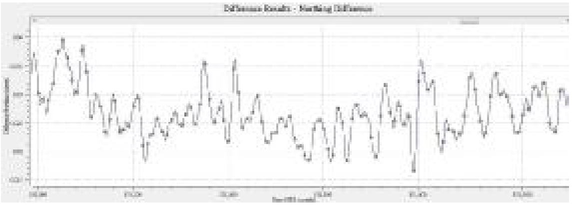

Trip 6: dN 0.075~0.106 m


Trip 5: dZ 0.110~0.150 m

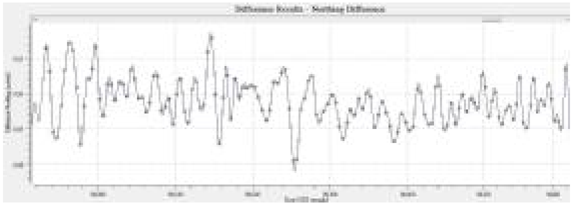

Trip 6: dZ 0.115~0.172 m


Trip 7: dE 0.006~0.033 m

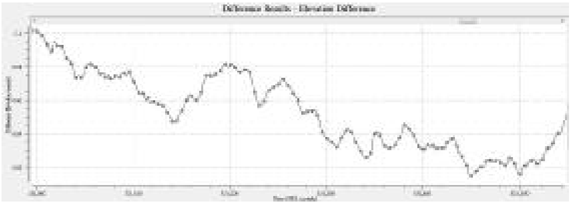

Trip 8: dE -0.060~-0.039 m



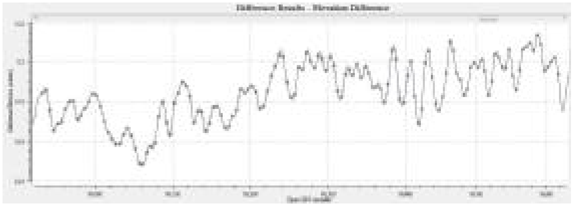
Trip 7: dN 0.017~0.040 m



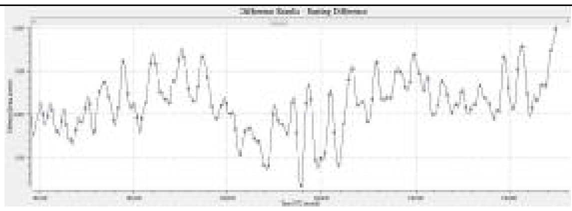
Trip 8: dN -0.062~-0.036 m



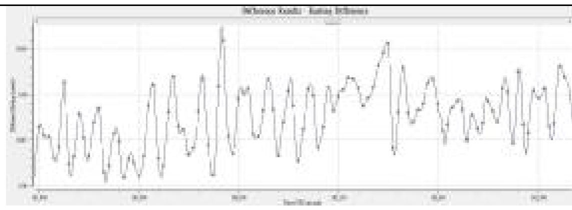
Trip 7: dZ 0.017~0.105 m



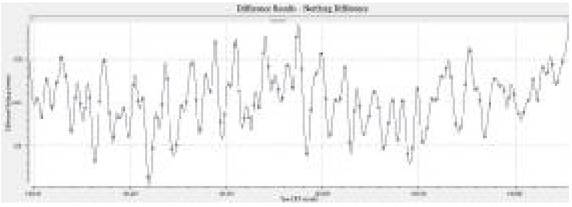
Trip 8: dZ 0.147~0.215 m



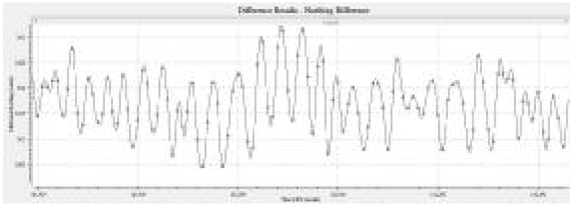
Trip 9: dE 0.077~0.095 m



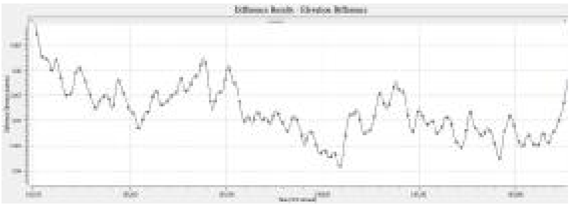
Trip 10: dE 0.080~0.097 m



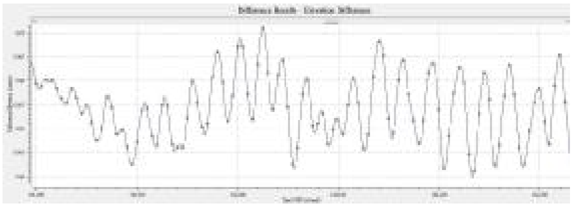
Trip 9: dN 0.006~0.023 m



Trip 10: dN 0.004~0.032 m



Trip 9: dZ 0.040~0.068 m



Trip 10: dZ 0.040~0.071 m

Figure 6: Differences of PPP trajectory as compared to DGPS trajectory

3-2 Comparison of point clouds RawLAS generated by DGPS and PPP

Point clouds of RawLAS stand for the results that raw laser data downloaded from the airplane are combined with trajectories to obtain geodetic coordinates of laser points whereas strips of point clouds are not adjusted between adjacent strips for survey block. Two datasets are generated by DGPS and PPP, separately. For making the comparison of the coordinates of identical point of a selected timestamp, 9 small sets of areas are selected. As shown in Figure 7, the 3 overlap zones of strips #7 and #8 with adjacent strips are considered. 3 small sets with an area of 100 m x 200 m are selected from the beginning, middle and end of each of the 3 overlap zones. The differences in the ENZ dimensions of DGPS and PPP results are compared for all the points in the selected small areas.

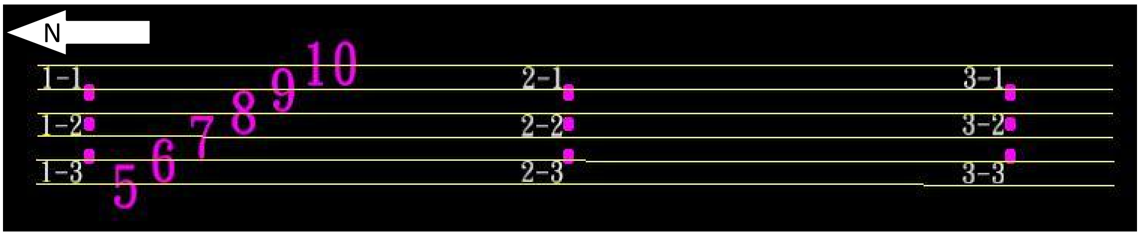


Figure 7: The sample areas for point clouds comparison

The results of DGPS approach are used as reference. Table 2 shows the difference between the results of DGPS and PPP in the respective small areas. Statistics used in this table include average, standard deviation, minimum, and maximum in the 3 dimensions. The average deviation in E direction is 0.082 m ranging from -0.025 m to 0.166 m; average in N direction is -0.219 m ranging from -0.551 m to 0.055 m; average in Z direction is -0.106 m ranging from -0.179 m to 0.002 m. In general, there is an absolute bias in ENZ directions of more than 0.082 m. In summary, the standard deviation of averages in all small areas in E direction is 0.016 m; in N direction is 0.062 m; and in Z direction is 0.021 m. It is noteworthy that in the sample areas of 1-2, 2-2, and 2-3, the deviations in N direction is about 0.15 m, which is larger than the standard deviation of averages.

Table 2: Differences of the RawLAS generated by PPP as compared to that by DGPS

Small area	**1-1**			**2-1**			**3-1**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	0.095	-0.370	-0.136	0.019	-0.409	-0.151	0.003	-0.525	-0.121
SD	0.005	0.009	0.003	0.002	0.011	0.003	0.022	0.014	0.003
Min	0.083	-0.388	-0.143	0.013	-0.429	-0.158	-0.025	-0.551	-0.130
Max	0.105	-0.350	-0.129	0.025	-0.389	-0.144	0.049	-0.490	-0.113
Small area	**1-2**			**2-2**			**3-2**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	0.125	-0.252	-0.077	0.064	-0.281	-0.130	0.077	-0.179	-0.103
SD	0.038	0.182	0.075	0.045	0.150	0.053	0.016	0.176	0.046
Min	0.071	-0.459	-0.161	0.028	-0.401	-0.173	0.049	-0.419	-0.179
Max	0.166	-0.064	0.002	0.131	-0.049	-0.048	0.104	0.009	-0.049
Small area	**1-3**			**2-3**			**3-3**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	0.140	0.036	-0.042	0.117	0.040	-0.089	0.098	-0.026	-0.104
SD	0.010	0.009	0.003	0.002	0.008	0.003	0.003	0.004	0.003
Min	0.125	0.018	-0.048	0.111	0.023	-0.097	0.046	-0.034	-0.111
Max	0.159	0.055	-0.034	0.125	0.053	-0.082	0.103	-0.010	-0.098
Combined 9 small areas									
	Average			**Min**			**Max**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	0.082	-0.219	-0.106	0.003	-0.525	-0.151	0.140	0.040	-0.042
SD	0.016	0.062	0.021	0.002	0.004	0.003	0.045	0.182	0.075
Min	-	-	-	-0.025	-0.551	-0.179	-	-	-
Max	-	-	-	-	-	-	0.166	0.055	0.002

3-3 Comparison of LAS after strip adjustment

All strips of #5 to #10 of point clouds generated by DGPS and PPP are adjusted separately. The sample areas for comparison are the same as RawLAS as shown in Figure 7. Table 3 shows the results of the differences of the LAS generated by PPP as compared to that by DGPS. The average of deviations in E direction is -0.026 m ranging from -0.080 m to 0.055 m; average in N direction is 0.104 m ranging from -0.010 m to 0.194 m; average in Z direction is 0.113 m ranging from 0.065 m to 0.152 m. There is obviously a bias in all ENZ directions. As shown by standard deviations, the bias in E direction is 0.008 m; in N 0.015 m; and in Z 0.004 m. When the results in Table 3 are compared with those of Table 2, it is shown that most of the biases are negative values in RawLAS datasets. Nevertheless, after strip adjustment, the biases in all ENZ directions are substantially reduced.

Table 3: Differences of the LAS generated by PPP as compared to that by DGPS

Small area	**1-1**			**2-1**			**3-1**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.054	0.011	0.090	0.002	0.089	0.113	0.033	0.161	0.106
SD	0.003	0.009	0.002	0.003	0.006	0.002	0.015	0.014	0.002
Min	-0.061	-0.010	0.086	-0.007	0.075	0.107	0.001	0.127	0.100
Max	-0.046	0.029	0.094	0.010	0.102	0.118	0.055	0.186	0.112
Small area	**1-2**			**2-2**			**3-2**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.056	0.117	0.083	-0.024	0.065	0.111	-0.006	0.062	0.124
SD	0.015	0.031	0.008	0.014	0.009	0.004	0.016	0.037	0.012
Min	-0.077	0.072	0.065	-0.047	0.044	0.106	-0.033	-0.009	0.107
Max	-0.032	0.185	0.093	-0.010	0.079	0.123	0.032	0.122	0.140
Small area	**1-3**			**2-3**			**3-3**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.073	0.167	0.100	-0.042	0.095	0.144	-0.017	0.168	0.147
SD	0.004	0.022	0.004	0.002	0.001	0.002	0.001	0.010	0.002
Min	-0.080	0.115	0.088	-0.046	0.090	0.138	-0.021	0.137	0.142
Max	-0.064	0.193	0.107	-0.037	0.098	0.149	-0.002	0.194	0.152

Combined 9 small areas									
	Average			**Min**			**Max**		
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.026	0.104	0.113	-0.073	0.011	0.083	0.033	0.168	0.147
SD	0.008	0.015	0.004	0.001	0.001	0.002	0.016	0.037	0.012
Min	-	-	-	-0.080	-0.010	0.065	-	-	-
Max	-	-	-	-	-	-	0.055	0.194	0.152

3-4 Comparison of combined adjustment of DGPS and PPP with DGPS-only

An adjustment with DGPS-adjusted strips of #5, #6, #9, and #10, and PPP-adjusted strips of #7 and #8 was carried out. Another results for reference is by adjustment of DGPS-only. Table 4 shows the comparison of differences of the LAS generated by combined DGPS and PPP as compared to that by DGPS-only. The sample areas for comparison are the same as RawLAS as shown in Figure 7. The average of deviations in E direction is -0.037 m ranging from -0.081 m to 0.039 m; average in N direction is 0.086 m ranging from 0.004 m to 0.200 m; average in Z direction is 0.055 m ranging from 0.009 m to 0.094 m. The absolute value bias is below 0.086 m.

As shown by standard deviations, the bias in E direction is 0.007 m; in N 0.014 m; and in Z 0.004 m. The discrepancy between the combined DGPS and PPP results and the DGPS-only results are relatively small. Therefore, both types of adjustments are comparable for generating LiDAR point clouds.

Table 4: Differences of the LAS generated by combined DGPS and PPP as compared to that by DGPS-only

Small area		**1-1**			**2-1**			**3-1**	
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.070	0.024	0.032	-0.012	0.099	0.054	0.017	0.172	0.047
SD	0.003	0.008	0.002	0.004	0.008	0.002	0.015	0.015	0.002
Min	-0.077	0.004	0.026	-0.022	0.082	0.049	-0.016	0.133	0.041
Max	-0.062	0.042	0.036	-0.003	0.113	0.058	0.039	0.200	0.053
Small area		**1-2**			**2-2**			**3-2**	
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.069	0.108	0.027	-0.039	0.065	0.058	-0.019	0.059	0.069
SD	0.009	0.023	0.011	0.009	0.013	0.003	0.020	0.035	0.010
Min	-0.081	0.070	0.009	-0.055	0.039	0.053	-0.053	0.006	0.053
Max	-0.051	0.152	0.040	-0.027	0.088	0.067	0.020	0.115	0.083
Small area		**1-3**			**2-3**			**3-3**	
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.071	0.087	0.035	-0.048	0.043	0.082	-0.020	0.118	0.089
SD	0.002	0.015	0.003	0.002	0.003	0.002	0.001	0.005	0.001
Min	-0.077	0.049	0.027	-0.052	0.036	0.076	-0.023	0.089	0.085
Max	-0.066	0.110	0.041	-0.043	0.050	0.087	-0.001	0.130	0.094
Combined 9 small areas									
		Average			**Min**			**Max**	
ENZ	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**	**dE**	**dN**	**dZ**
Average	-0.037	0.086	0.055	-0.071	0.024	0.027	0.017	0.172	0.089
SD	0.007	0.014	0.004	0.001	0.003	0.001	0.020	0.035	0.011
Min	-	-	-	-0.081	0.004	0.009	-	-	-
Max	-	-	-	-	-	-	0.039	0.200	0.094

4. CONCLUSIONS AND SUGGESTIONS

Basically, DGPS approach is different from PPP approach in both datum and computation procedures. A differences of trajectories by DGPS and PPP range from 0.004 m to 0.215 m. Obviously, the difference is substantial.

The results of this study show that the differences of trajectories obtained by DGPS and PPP can be around 0.2 m. And, subsequently, the differences of coordinates of RawLAS generated on basis of respective trajectories exhibit similar magnitude. However, after strip adjustment, the deviation of PPP results from DGPS results becomes substantially smaller roughly 0.1 m. And, the standard deviation of the deviation become negligible.

The combined adjustment with strips of PPP and DGPS results was tested in this study. The deviation of the combined results from that of DGPS-only results is smaller 0.1 m. This indicates that when ground GPS stations are not available, PPP can be a good substitute. For the production of 1 m grid with accuracy requirement of 0.3 m, this strategy is proved to be effective.

More studies need to be done for drawing conclusions in the similarities of PPP and DGPS. More different combinations in a larger study area can be tested to further solidify the conclusion drawn in this experiment. In addition, measurements of ground truth can be used to check the accuracy of PPP and DGPS results and thus to understand more messages of absolute accuracy rather than relative accuracy.

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