STRIPE ADJUSTMENT OF AIRBORNE LIDAR DATA USING GROUND POINTS

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Abstract: LiDAR combines a laser scanner, a rover GPS, an IMU, and a ground GPS base stations for collecting a large number of high-density and high-precision point cloud in a short period of time. Although correction parameters of the systematic error by boresight calibration process are used for generating point clouds, the positioning accuracy is still affected in the survey area by local factors such as terrain and weather conditions and GPS uncertainties. Due to the GPS environmental conditions, changes in aircraft flight attitude along with Heading, Roll, Pitch and Height and other factors, adjacent strips show discrepancies in their overlapping zones. For removing these discrepancies, strip adjustment methods can be used to calculate the matching or differences in the strip overlap area. Then, the parameters of system error can be derived to correct the coordinates of point cloud. In this study, except for the exploration on the system error between the flight strips, two different practices in the strip adjustment also consider, including the adjustment with or without known ground points. Two sets of calibration parameters can be calculated for deriving two sets of corrected point cloud data. Finally, an accuracy assessment of strip adjustment results are given in this paper. The experimental results indicate no matter whether the ground measured points are added or not, the outcomes after adjustment can achieve good accuracy. Although the internal precision analysis between the two different adjustment is almost the same, but the adjustment result with the known ground points is better than that without ground points. It is concluded that for airborne LiDAR survey ground control points are not really necessary for inclusion in the strip adjustment process in case that boresight calibration has been properly carried out.

1. INTRODUCTION

A LiDAR system is consisted of many subsystems, including GPS, IMU, and laser scanner. Error sources might be originated from the flight attitude, GPS positioning, weather conditions, and system integration. The spatial data generated from the LiDAR system will usually present a certain amount of systematic error. The error affects not only the absolute accuracy of the coordinates of the 3D point cloud, but also cause a displacement of adjacent flight strips shown as Figure 1. The displacement will affect the quality of spatial products, e.g. Digital Terrain Models.

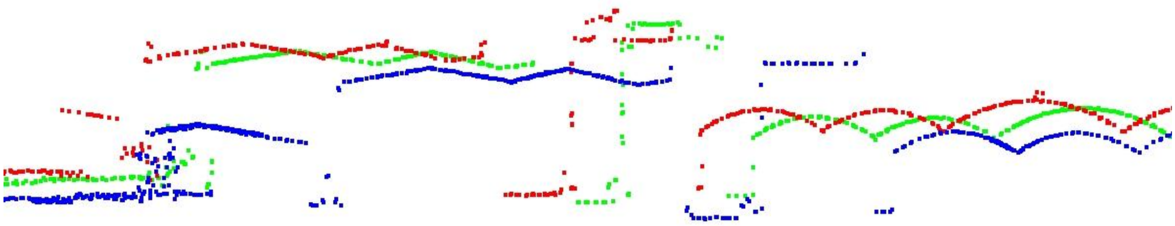

Figure 1: The profile of point clouds of three adjacent strips before adjustment.

Strip adjustment is a common method used to eliminate aforementioned systematic error. Its usage is to assure the quality of final spatial data after calibration. Collection of ground point data is a tough task in the high mountain terrains in Taiwan. Whether it is critical to include ground points in the process of strip adjustment become important in the management of a data acquisition project. Therefore, the purpose of this study is aimed to explore the effect of ground points in the process of strip adjustment.

2. METHODOLOGY

Figure 2 shows the flow of all the steps adopted in this paper. This is comparable with that applied earlier in Taiwan by Chen and others (Chen et al., 2005). The steps include:

(1) LiDAR data acquisition and preprocessing: To collect point clouds, trajectory files, check points, and control points for the study area.
(2) Point cloud filtering for ground points: also referred as lidar data classification. This is to filter out non-ground points and keep only the ground points (also called bare-earth points) in each strip.
(3) Strip adjustment with or without GCPs: For solving calibration parameters including dz, dr, dp, and dh for each strip by TerraMatch software.
(4) Point clouds for each strip: For generation of final point clouds by applying the calibration parameters. Result of Set A is with GCPs and that of Set B is without GCPs.
(5) Accuracy assessment: To evaluate the internal accuracy after adjustment and external accuracy using check points.

TerraMatch developed by TerraSolid Co. can be used to correct POS (positioning and orientation) errors in an airborne LiDAR system. The correction can be applied to the entire set of point clouds collected in a flight block, or to each flight strip separately (Arttu, 2004). The key features of the TerraMatch include

(1) Automatic correction of LIDAR point cloud data,
(2) Rigorous error model for the orientation parameters,
(3) Least squares method for the azimuth error correction,
(4) Two options of observation data (elevation or intensity),
(5) Geometric structural adjustment of laser scanning using area-based matching,
(6) Gross error debug by using ”Data-snooping” technique.

The algorithm of strip adjustment applied in TerraMatch can be referred to a theory proposed by Burman (2002). The difference between the overlapping strips is seen as positioning, orientation errors, and the placement error between the IMU and a laser scanner is also considered. In the algorithm, the discrete point cloud is rasterized. Then the coordinates of ground points are computed iteratively with elevation and intensity values in the overlapping area. The mathematic model of this algorithm can be represented as following equation (1)

$$\lambda_{Zi} = Z'_X \cdot dX_0 + Z'_Y \cdot dY_0 - dZ_0 + \left(Z'_X \frac{\partial Rx}{\partial r} + Z'_Y \frac{\partial Ry}{\partial r} - \frac{\partial Rz}{\partial r}\right) \cdot \begin{pmatrix} l_x \\ l_y \\ l_z \end{pmatrix} \cdot dr + \left(Z'_X \frac{\partial Rx}{\partial r} + Z'_Y \frac{\partial Ry}{\partial r} - \frac{\partial Rz}{\partial r}\right) \cdot \begin{pmatrix} l_x \\ l_y \\ l_z \end{pmatrix} \cdot dp + \left(Z'_X \frac{\partial Rx}{\partial r} + Z'_Y \frac{\partial Ry}{\partial r} - \frac{\partial Rz}{\partial r}\right) \cdot \begin{pmatrix} l_x \\ l_y \\ l_z \end{pmatrix} \cdot dh \quad (1)$$

where λ_{Zi} is the difference of elevation for measured points and one for check points,

$(dX_0, dY_0, dZ_0)^T$ is an initial vector for the displacement, and it will be updated during the iteratively computation,

(r, p, h) means a vector consisted of three attitude parameters, e.g. roll, pitch, and heading,

(dr, dp, dh) is a vector for the attitude angle deviations, and it will also be updated during the iteratively computation.

In the internal accuracy assessment, the average magnitude was used as a quantitative index to compute the average of elevation difference between matching points in a strip and their corresponding points in adjacent points by the MeasureMatchfunction (Arttu, 2004). For external accuracy assessment, the errors are calculated by GCPs. And, the differences between laser points and GCPs are tabulated by the function of Output control report in TerraScan (Arttu, 2004).

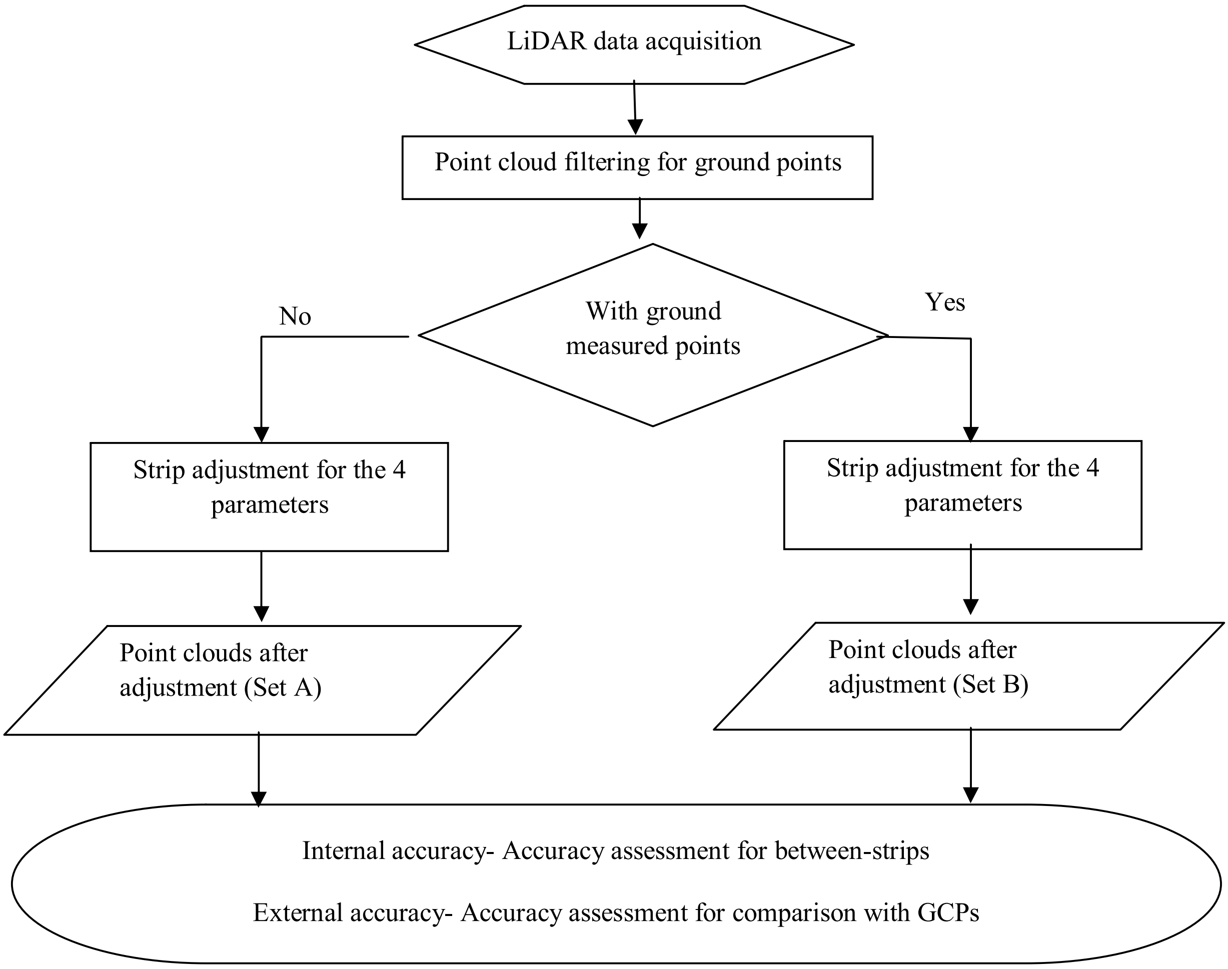

Figure 2: Workflow of strip adjustment

3. CASE STUDY

The study area (Figure 3), an area of 7.23 km^2, is located in the mountain area near a reservoir of southern Taiwan. There are seven strips cover the test site, and the overlap rate is about 50%. The flight altitude is 3000 meters, and field of viewing angle (FOV) was 35 degrees. The weather was good during scanning. A LEICA ALS 60 scanner was used. Total number of point clouds is about thirteen million points, and the average point density of about 1.8/m^2. As shown in Figure 4, there are 24 ground points measured in a field survey for the strip adjustment of 24 points. As shown in Figure 5, there are 50 ground points used as check points for assessing the external accuracy after adjustment accuracy..

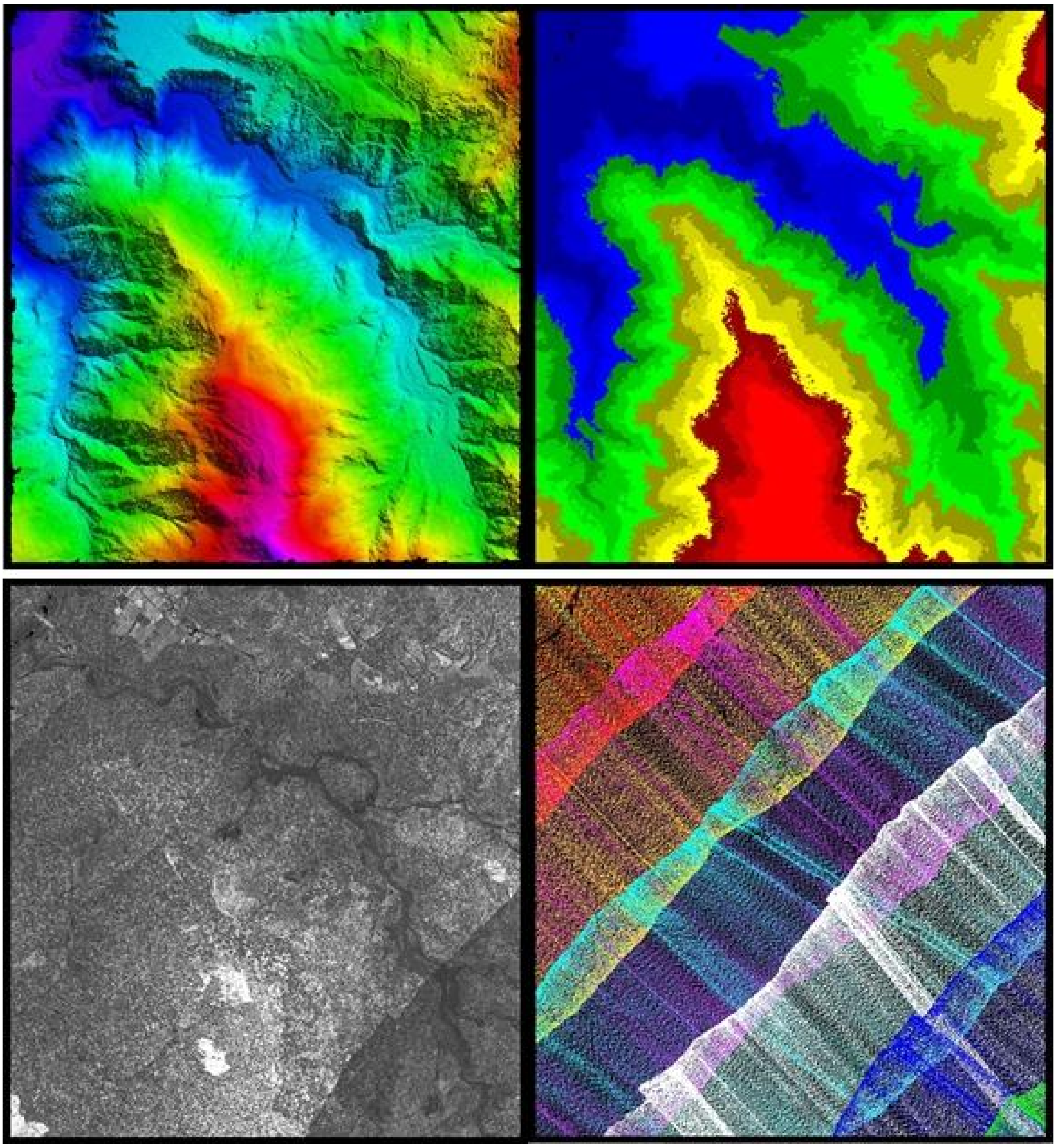

Figure 3: The results of LiDAR survey of the study area. Top images are coded with elevations; Lower-Left image is coded with intensity and Lower-right is coded with flight strip nomination.

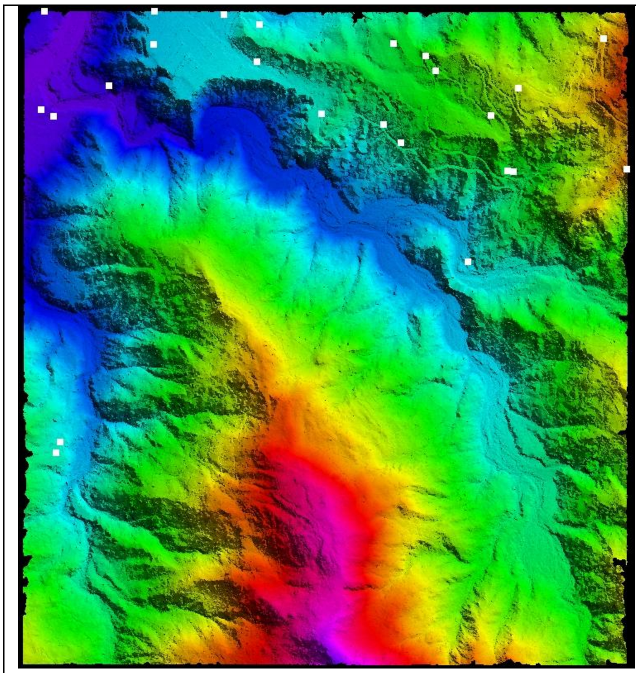	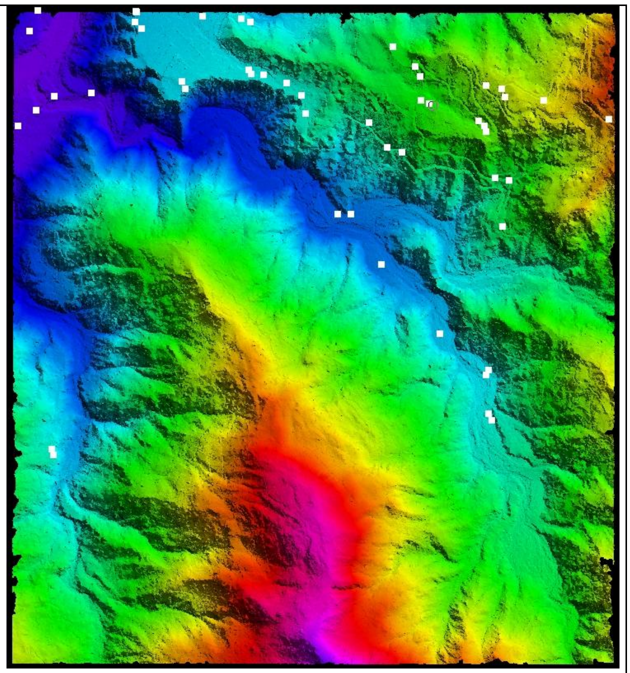
Figure 4: The distribution of measured known ground points (24 points)	**Figure 5:** The distribution of check points (50 points) in the test

4. RESULTS

According to the experimental procedures previously described (Figure 2), two sets of adjustment results can be derived. One set of results is obtained without measured ground points (set A), and one with known ground points (set B), respectively. Moreover, the elevation of 50 check points is used to compare with point cloud data of set A and set B. The results of the elevation comparison between check points and Set A and Set B are given in Table 1. The order in the table 1 is the elevation before adjustment, and the elevation of set A and set B of the corresponding point. Table 2 shows the statistics of the 3 sets of points when compared with ground check points given in Table 1. The statistics indicate that the average elevation difference (dz) of raw data with check points is 19.5 cm, which means the systematic error occurred in the raw data. Moreover, the elevation accuracy of set A result after strip adjustment without ground points constrained approached to 3.1 cm. It shows that the adjustment result is good enough to satisfy the accuracy requirements in general. However, the elevation accuracy of 1.9 cm of set B result with ground points constrained is even better than one for the set A. But the difference is not substantial.

Finally, the internal accuracy assessment is shown as Table 3 and Figure 6. The horizontal axis in the figure is the strip number, and vertical axis is the elevation difference value for three sets of results. It is shown that strip adjustment can effectively improve internal accuracy. Following conclusions can be drawn:

1. The raw point clouds in the overlapping region of scanning strips containing systematic error.
2. The strip adjustment can effectively improve the internal accuracy of scanned data.
3. The amount of error of the edge portion of the flight strip is slightly higher.
4. The best experimental result can be given under the adjustment with measured ground points constrained.

Table 1: Elevation comparison for the check points with set A and set B.

Number	Known Z	Laser Zr	Dzr	Laser Za	Dza	Laser Zb	Dzb
1	482.051	482.239	0.188	481.936	-0.115	482.005	-0.046
2	485.794	485.86	0.066	485.834	0.04	485.706	-0.088
3	298.864	299.11	0.246	298.897	0.033	298.881	0.017
4	486.367	486.606	0.239	486.333	-0.034	486.349	-0.018

5	482.56	482.913	0.353	482.626	0.066	482.669	0.109
6	590.845	590.892	0.047	590.631	-0.214	590.649	-0.196
9	464.802	464.892	0.09	464.775	-0.027	464.769	-0.033
10	464.893	465.01	0.117	464.887	-0.006	464.898	0.005
11	626.655	626.957	0.302	626.704	0.049	626.754	0.099
12	622.865	623.052	0.187	622.779	-0.086	622.906	0.041
13	683.678	683.878	0.2	683.622	-0.056	683.747	0.069
14	682.42	682.68	0.26	682.419	-0.001	682.542	0.122
15	442.643	442.635	-0.008	442.502	-0.141	442.452	-0.191
16	442.799	442.389	-0.41	442.326	-0.473	442.329	-0.47
17	467.053	467.069	0.016	466.765	-0.288	466.795	-0.258
18	470.434	470.66	0.226	470.349	-0.085	470.395	-0.039
19	516.974	516.889	-0.085	516.689	-0.285	516.647	-0.327
20	521.343	521.319	-0.024	521.081	-0.262	521.058	-0.285
21	549.803	549.803	0	549.554	-0.249	549.661	-0.142
22	548.859	548.71	-0.149	548.481	-0.378	548.578	-0.281
23	310.149	310.274	0.125	310.168	0.019	310.213	0.064
24	294.096	294.367	0.271	294.274	0.178	294.268	0.172
25	444.909	445.259	0.35	445.022	0.113	444.963	0.054
26	468.644	469	0.356	468.712	0.068	468.726	0.082
27	401.23	401.547	0.317	401.309	0.079	401.32	0.09
28	410.112	410.429	0.317	409.981	-0.131	410.24	0.128
29	443.269	443.377	0.108	443.088	-0.181	443.193	-0.076
30	460.736	460.67	-0.066	460.35	-0.386	460.604	-0.132
31	479.837	479.923	0.086	479.678	-0.159	479.866	0.029
32	595.872	596.486	0.614	596.182	0.31	596.176	0.304
33	570.956	571.391	0.435	571.143	0.187	571.141	0.185
34	461.963	462.088	0.125	461.972	0.009	461.973	0.01
35	510.899	511.604	0.705	511.335	0.436	511.517	0.618
36	624.64	625.422	0.782	625.012	0.372	625.157	0.517
37	667.425	667.869	0.444	667.61	0.185	667.789	0.364
38	705.163	705.465	0.302	705.185	0.022	705.295	0.132
39	766.004	766.291	0.287	766.057	0.053	766.176	0.172
40	298.691	298.715	0.024	298.612	-0.079	298.588	-0.103
41	306.343	306.523	0.18	306.383	0.04	306.386	0.043
43	450.804	451.002	0.198	450.917	0.113	450.903	0.099
44	478.38	478.601	0.221	478.354	-0.026	478.354	-0.026
45	397.215	397.166	-0.049	396.864	-0.351	396.929	-0.286
46	460.899	461.024	0.125	460.85	-0.049	460.951	0.052
47	475.329	475.669	0.34	475.27	-0.059	475.401	0.072
48	548.095	548.244	0.149	547.973	-0.122	548.133	0.038

49	589.441	589.682	0.241	589.432	-0.009	589.45	0.009
50	460.54	460.86	0.32	460.671	0.131	460.727	0.187

Table 2: Elevation accuracy statistics for the check points (a order of raw data, set A, and set B)

	Raw	A	B
Average dz	0.195	-0.031	0.019
Minimum dz	-0.41	-0.473	-0.47
Maximum dz	0.782	0.436	0.618
Average magnitude	0.229	0.142	0.146
Root mean squares	0.286	0.189	0.201
Std deviation	0.212	0.189	0.202

Table 3: Internal accuracy comparison for each strip

Raw	Average Magnitude：		0.31803
Strip #	Points	Magnitude	Dz
17	136801	0.3226	0.2378
18	401229	0.2643	0.0213
19	727342	0.2908	-0.1129
20	759510	0.3241	0.1794
21	400464	0.3804	-0.2338
22	171571	0.3706	0.02
23	21046	0.4158	-0.238
Set A	Average Magnitude：		0.24515
Strip #	Points	Magnitude	Dz
17	137211	0.198	0.05
18	402790	0.2164	0.0749
19	730484	0.2499	-0.0049
20	760574	0.251	0.0045
21	400595	0.268	-0.0819
22	174251	0.2368	0.0023
23	21493	0.3579	-0.2077
Set B	Average Magnitude：		0.27384
Strip #	Points	Magnitude	Dz
17	136711	0.3068	-0.048
18	400977	0.2925	0.036
19	728641	0.2647	0.0127
20	760788	0.2633	0.0047
21	400736	0.2728	-0.0426
22	172154	0.2771	0.0006
23	21035	0.3929	-0.1774

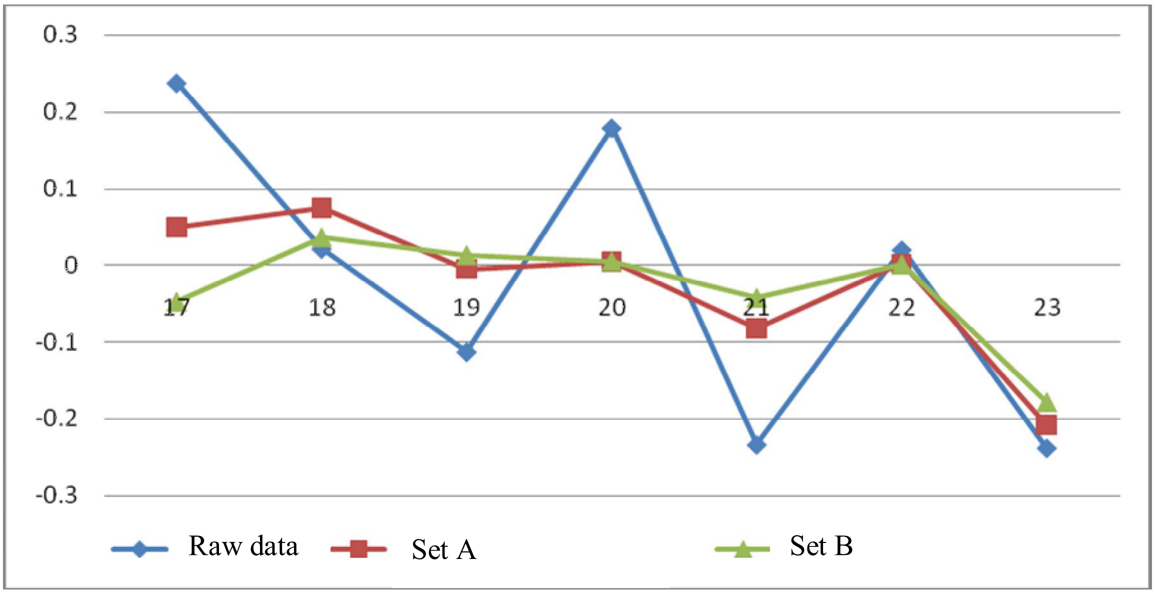

Figure 6: diagram showing the internal accuracy of each of the 7 strips

5. CONCLUSIONS AND RECOMMENDATIONS

The statistical results indicate that the average elevation difference (dz) of raw data before strip adjustment was worse than those after strip adjustment, which means the systematic error occurred in the raw data. Therefore, the strip adjustment is a necessary process for the airborne LiDAR data. Moreover, the adjustment results can meet the accuracy requirements of LiDAR data processing specification, no matter with or without constrained with ground measured points. With the inclusion in strip adjustment can give better results than without the ground measured points. It is therefore suggested to use if ground measured points are available.

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