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EXAMPLE OF THE ASSESSMENT OF DATA INTEGRATION ACCURACY ON THE BASE OF AIRBORNE AND TERRESTRIAL LASER SCANNING

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ABSTRACT Light detection and ranging (LiDAR) technology has changed conventional approach to the spatial data acquisition. Unusually amount of the measurements points with extremely high precision are now available from generally two platforms: airborne (Airborne Laser Scanner - ALS) and terrestrial (Terrestrial Laser Scanner - TLS). There are however some gaps in these products, in ALS - on vertical surfaces and in TLS - on horizontal one. The reason is that these laser systems register the same object from different points in space. Integration of the data obtained for airborne and terrestrial platforms can fulfil the gaps. The aim of the research presented in the paper was comparing the matched ALS and TLS data to the in-situ total station (TS) measurements. Different test areas were chosen: placed on horizontal, vertical or inclined surfaces and covered by grass or asphalt pavement. Point's positions obtained from ALS, TLS and TS measurements are analysed together. TS measurements are taken as a reference. ALS and TLS point position accuracy analysis based on these perpendicular distance from the plane defined by the nearest three non-collinear TS points. The discrepancies were further statistically analysed.
In conclusion can be stated that some bias was observed in ALS data, they are below TLS and TS points as well. Besides more significant discrepancy between TS points are observed for ALS points in compare to the TLS one, confirming our expectations.

1. INTRODUCTION

LIDAR data registered form airborne platform ALS is characterized by the lack of information on the vertical surfaces. Against, using TLS technology it is impossible to register high placed horizontal planes (for example – building roofs). Therefore the integration of the two kinds of registration is the subject of research in the last years. The projects are focused on the integration algorithms and on the accuracy assessment. Some information about the ALS and TLS data integration can be found (Hansend et al., 2008; Jochem et al., 2011; Miller, 2008; Vosselman 2009, 2010). The test area depends on the scientist' interests, besides common applications in urban area one can find usage the LIDAR data integration in coastal area monitoring (Miller 2008) or for extraction of vertical walls from Mobile Laser Scanning data for solar potential assessment (Jochem et al., 2011).

The LIDAR data become more and more popular also in Poland. For example in 2006 ALS data are gathered for Cracow. It was an inspiration for preparing also terrestrial measurements for some test area using TLS.

Data integration is the problem per se, but the question about the accuracy of the final product comes directly out. The spatial accuracy is one of the five components of the standards according to ISO 19113 quality of data. In our research we concentrated on the spatial accuracy of the integrated data from ALS and TLS. To investigate the spatial accuracy, the LIDAR clouds of points were compared with conventional measurements (surveying using total station).

2. TEST SITE AND METHODOLOGY

The test site was located in the centre of Cracow in Poland, near the heart of the city – the Wawel castle and Vistula river meander. The test area is important from at least two points of view: historical heritage, monuments and also because of flood risk. ALS data was obtained from Municipality of Cracow. ALS data were acquired by FLI-MAP system, on behalf of the Municipality of Cracow in 2006. Files obtained from the Municipality of Cracow in ASCII format contained only the coordinates X, Y, Z of points and the RGB values assigned to each point. ALS data was registered in Cracow Local Coordinates System (CLCS). TLS data was gathered for the purposes of the researches. TLS data set consisted of 47 scans obtained using the Riegl scanner VZ-400 in June and October 2010. The TLS scans were combined together in the project coordinate system (PRCS) using Multi Station Adjustment function in the Riegl software. We obtained in this way standard deviation of 0.006 m between neighbouring scans. In order to analyze the two clouds together we decided to transform TLS data form PRCS into CLCS - the same as ALS data. For this purpose all positions of the scanner were measured (in CLCS) using a total station. In the next step we transformed the data from the PRCS to CLCS using the built-in features RiScanPro, used 23 points (scanner positions). We obtained the standard deviation of the matching of 0.0219 m.
The aim of the research presented in the paper was comparing the matched LIDAR data to the in-situ total station measurements. Therefore in the following step we compared the position of selected test areas from the ALS data, TLS data and direct measurement. The test areas were different: some of them was placed on horizontal surfaces, some on vertical one (in two difference planes), some inclined, covered by grass, on asphalt pavement and on the top of the bridge. Accuracy analysis of the test fields has shown the differences between ALS, TLS and surveying data. It has also demonstrated which areas are the best for using them to the integration of ALS and TLS data. These fields can be used to correct fitting ALS data into TLS data in CLCS.

2.1 Description of the test areas

For the accuracy analysis 8 test areas were chosen (Table 1). Each area consists of rectangle and the additionally point in the centre of this rectangle. In this geometric structure we have

4 triangles. For all subsequent analysis for every test area only one triangle from those fours was used. All five points were measured by total station. Details about test field are presented in Table 1.

Tab.1. Descriptions of test areas

Name of test field	**Arrangem ent of plane**	**Type of surface**	**Other informatio n**
P1	Horizontal	Asphalt	Bridge
P3	Inclined	Grass	
P4	Horizontal	Grass	
P5	Horizontal	Asphalt	Pavement
P6	Vertical	Brick	P6 ⊥ P7
P7	Vertical	Brick	P6 ⊥ P7
P8	Horizontal	Asphalt	Pavement
P10	Vertical	Stone	

The location of vertical test areas were also shown on images Figure 1 and 2.

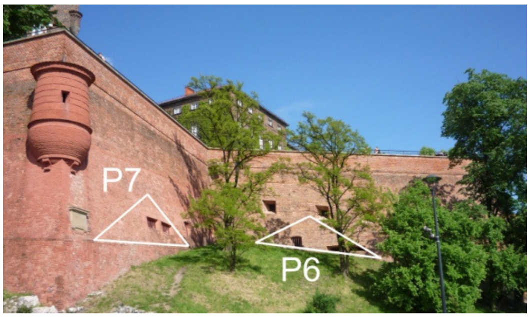

Fig. 1. Vertical test areas (P6 and P7) placed on the wall of Wawel Castle

Fig. 2. Vertical test areas (P10) placed opposite to the Wawel Castle on the wall of Vistula river embankments

In the Table 2 details of test areas are presented: area of the triangle, number of ALS and TLS points.

Tab. 2. Details of the test areas

Triangle from test field named	**Area of triangle [m^2]**	**Number of points ALS data**	**Number of points TLS data**
P1	13.92	128	553500
P3	12.22	167	967
P4	21.26	299	5353
P5	19.14	446	330461
P6	16.03	64	9745
P7	5.97	33	5648
P8	11.44	266	1809
P10	3.41	9	95194

2.2 Accuracy calculations

For each test area one creates the plane basing on the points measured by total station. To compare total stations measurements with clouds of points (ALS and TLS) the distance between reference plane and these two sets of data should be calculated (3).

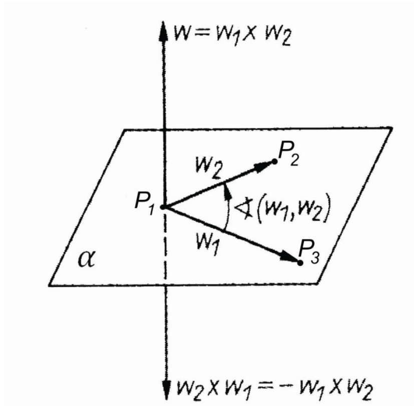

Fig. 3. Vectors W_1, W_2 and their vector product

Each test area is understood as a triangle composed of the vertexes named: P_1, P_2 and P_3. Point P_1 is the first and P_3 is the end of the vector W_1. The similar is for vector W_2. Finally the vector W is calculated from vectors W_1 and W_2.

The plane can be determined by three non-collinear points. The vertexes in triangle meet this condition. Vectors P_1-P_3 (W_1) and P_1-P_2 (W_2) describe this plane and allow calculating normal vector (Figure 3.)

$$W = W_1 \times W_2 = [A, B, C] \tag{1}$$

We can calculate the general plane equation α (2) using normal vector (W) (1):

$$\alpha: Ax + By + Cz + D = 0 \tag{2}$$

where: $A^2 + B^2 + C^2 > 0$.
In the next step cloud of LIDAR point are analysed for extraction only points "belonging" to the triangle. The constructed triangles are moved along their normal vector selecting the LIDAR points overlaying on them. Points inside moving triangle were collected in separate set. The distance between plane α and point $P_0 = (x_0, y_0, z_0)$ was calculated for each point from the set using equation (3).

$$d = \frac{|Ax_0 + By_0 + Cz_0 + D|}{\sqrt{A^2 + B^2 + C^2}} \tag{3}$$

The plane of the constructed triangle, on the basis of total station measurements, is assumed as the reference. The distances (difference) from the ALS and TLS clouds of points, and reference plane are statistically analysed. Minimum and maximum of the differences are calculated. Mean difference, standard deviation (SD), and 95% confidence level were also calculated. Besides, the histograms of the differences were also analysed. Some others spatial analyses were also performed: LIDAR clouds of points were colorized by the corresponding differences and the profiles presenting ALS, TLS with the reference planes as a background were also constructed.

3. RESULTS

Summary statistic for differences between reference plane and ALS is presented in Table 3, and for TLS in Table 4. Analysing the data for ALS systematic error is observed, average of the mean difference is -0.16 m, so the ALS data are mainly below the reference planes. Average of standard deviation is 0.09 m for ALS concerning reference plane.
For TLS data average of the mean difference is 0.004 m (but 5 of 8 test areas are however above the reference plane), and standard deviation: 0.03m.
Histograms of distances, differences between the reference plane from total station a LIDAR cloud of points for test area P4 - horizontal - are placed on (Figure. 4 - ALS and Figure 5 - TLS). For ALS data some bias can be noticed as a shift left (mean difference -0.068m). For TLS significant sift right can be seen in this case (mean difference 0.182 m). Corresponding histograms for test areas: P10 and P7 are presented in Figures: 6-9. These test areas are vertical and specific histograms can be found for ALS data. Some bias can be also noticed on Figure 9 for TLS measurements of test area P7.

On Figure 10 test area: P4 are colorized according differences of reference heights minus ALS and TLS.

On Figures 11 and 12 ALS/TLS clouds of points colorized by corresponding differences between the height of reference plane and of ALS/TLS are presented for test area P5. Test area P5 is horizontal, well fitted to the TLS data, the 95% of differences are between <-0.058 m;-0.024 m> (Table 4). For ALS the 95% of differences for test area P5 are bigger <-0.261;-0.682> (Table 3). But in both cases significant bias is observed, they are above the reference plane.

Profiles of the test' areas: P3 and P8 are presented in Figure 13 and 14. For test area P3 ALS cloud of points is placed below the reference plane and TLS above it. For the test area P8 both ALS and TLS points are located below the reference one, but ALS points are higher than TLS.

Tab. 3. Summary statistic for differences between reference plane and ALS

	min	**max**	**mean**	**SD**	**95% of data interval**
P1	-0.150	0.347	-0.039	0.069	<-0.135;-0.134>
P3	-0.522	-0.143	-0.353	0.083	<-0.486;-0.193>
P4	-0.178	0.014	-0.068	0.036	<-0.137;0.000>
P5	-0.275	-0.046	-0.161	0.053	<-0.261;-0.682>
P6	-0.464	0.400	0.204	0.250	<-0.447;0.390>
P7	-0.194	-0.123	-0.157	0.021	<-0.192;-0.124>
P8	-0.135	0.050	-0.040	0.043	<-0.123;0.034>
P10	-0.888	-0.270	-0.704	0.223	<-0.882;-0.292>

Tab. 4. Summary statistic for differences between reference plane and TLS

	min	**max**	**mean**	**SD**	**95% of data interval**
P1	-0.007	0.095	0.015	0.006	<0.003;0.026>
P3	-0.190	0.650	0.082	0.154	<-0.128;0.452>
P4	0.064	0.342	0.182	0.047	<0.096;0.286>
P5	-0.058	-0.003	-0.049	0.004	<-0.058;-0.024>
P6	-0.075	0.035	-0.012	0.009	<-0.031;0.005>
P7	-0.074	-0.012	-0.036	0.008	<-0.053;-0.023>
P8	-0.141	-0.087	-0.118	0.013	<-0.136;-0.093>
P10	-0.082	0.022	-0.026	0.019	<-0.065;0.027>

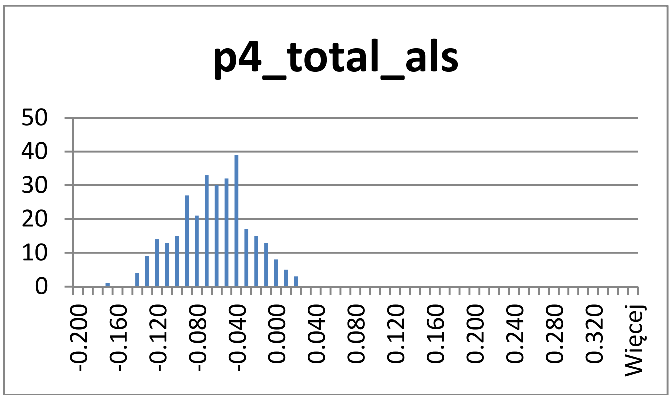

Fig. 4. Differences between reference heights (total station) and ALS – test area P4

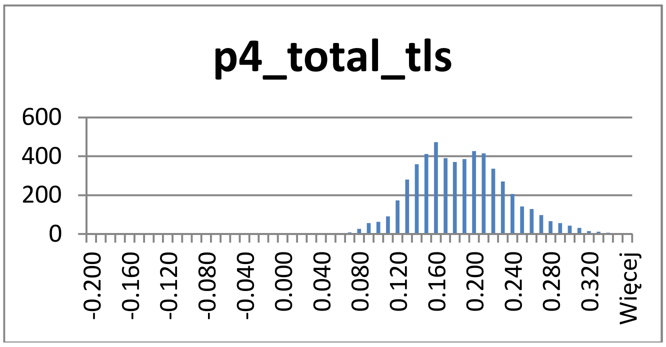

Fig. 5. Differences between reference heights (total station) and TLS – test area P4

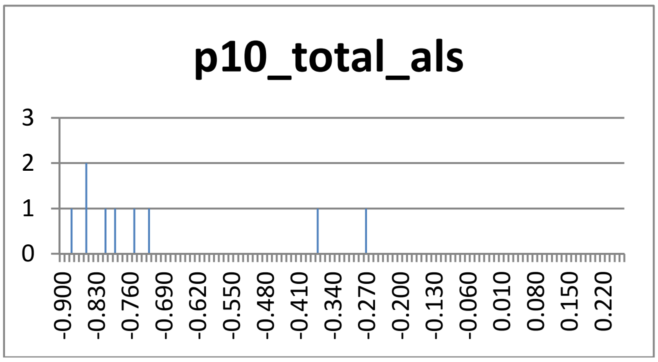

Fig. 6. Differences between reference heights (total station) and ALS – test area P10

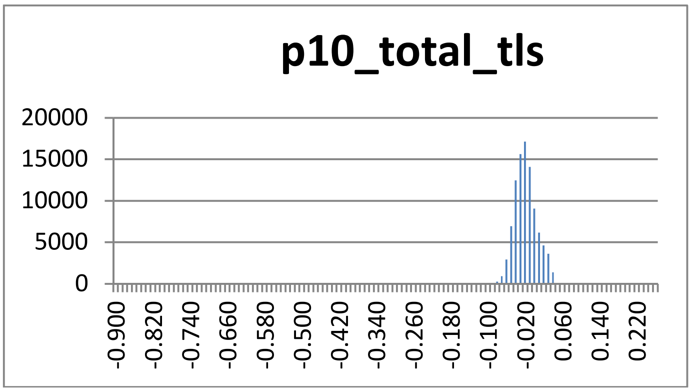

Fig. 7. Differences between reference heights (total station) and TLS – test area P10

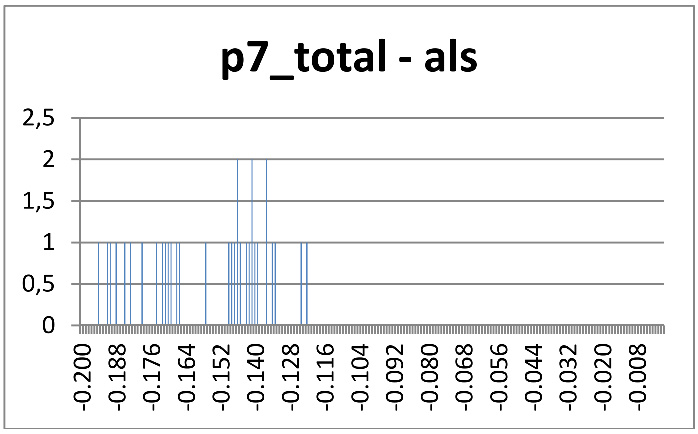

Fig. 8. Differences between reference heights (total station) and ALS – test area P7

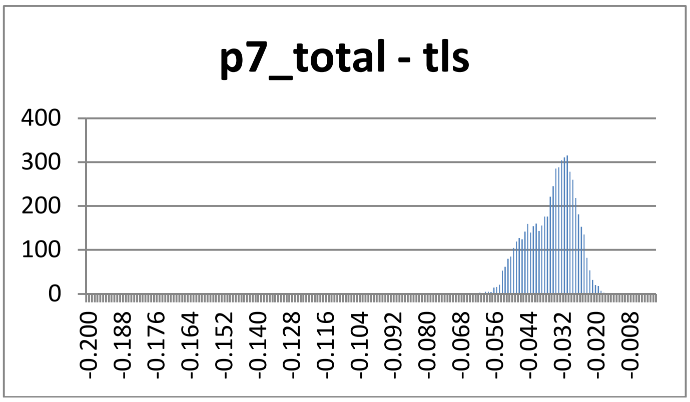

Fig. 9. Differences between reference heights (total station) and TLS – test area P7

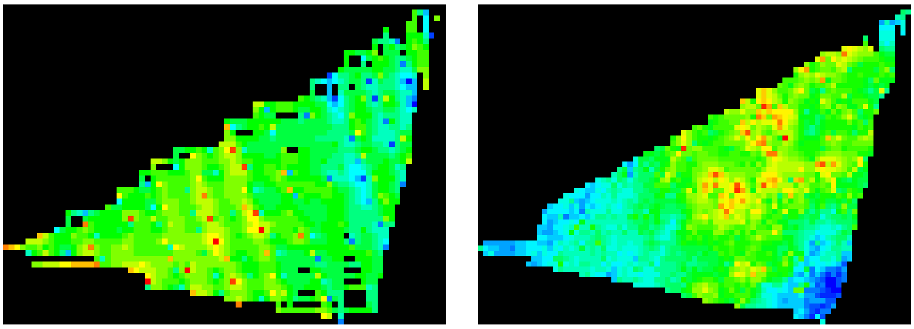

Fig. 10. Test area colorized according differences of P4 – gridded by pixel size of 0.1m (left – reference minus ALS, right – reference minus TLS (dark blue: lowest value, red: the highest value)

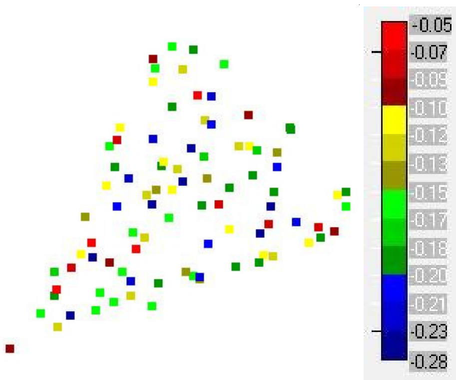

Fig. 11. ALS cloud points colorized by differences: reference plane minus ALS – test area P5.

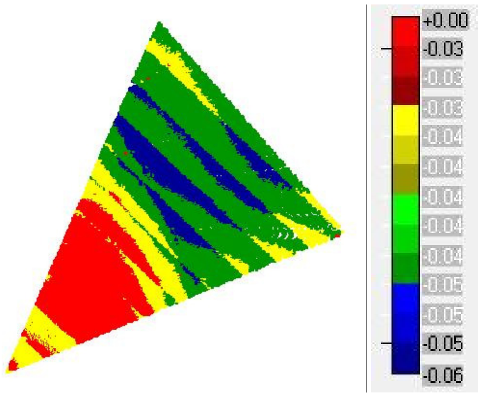

Fig. 12. TLS cloud points colorized by differences: reference plane minus TLS – test area P5

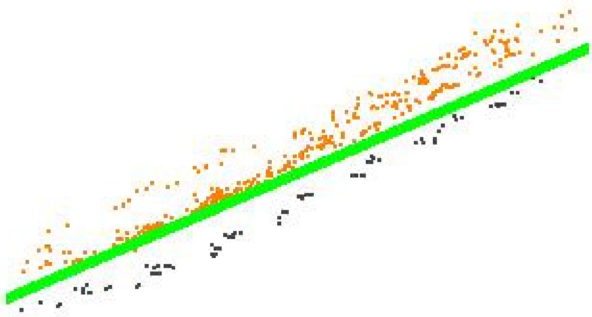

Fig. 13. Profile of test area - P3, green line – reference plane, dark points – ALS data, orange points TLS data.

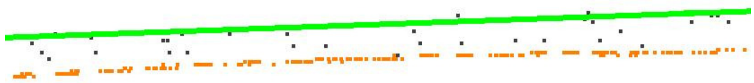

Fig. 14. Profile of test area - P8, green line – reference plane, dark points – ALS data, orange points TLS data.

4. CONCLUSIONS

According our initial research concerning the ALS and TLS integration the following conclusions can drown about their comparison with total station measurements:

1. ALS is placed below the TLS and total station measurements.
2. Bigger dispersion of the points can be observed on the profiles of ALS in compare with TLS.
3. The results of ALS data for all flat test areas are satisfying.
4. For vertical walls:
    a. Results of ALS for P7 and P10 are week, because plane of the reference area was perpendicular to the helicopter flight line (wall was parallel to the laser beam).
    b. However plane of P6 was perpendicular to the laser beam, and the results were much better.

So, the best areas which can be used to the integration of ALS and TLS data, should be similar to areas P5, P7 and P8.

Our research also confirms that the density map should be integral part of the scanning final product. Further studies are plan for the adjustment of ALS and TLS data.

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