Postprint of: Inglot A., Tysiąc P., Airborne Laser Scanning Point Cloud Update by Used of the Terrestrial Laser Scanning and the Low-Level Aerial Photogrammetry,
2017 Baltic Geodetic Congress (Geomatics) Gdansk University of Technology • 22-25 June 2017 • Poland • DOI: 10.1109/bgc.geomatics.2017.75

Airborne Laser Scanning Point Cloud Update by Used of the Terrestrial Laser Scanning and the Low-Level Aerial Photogrammetry

Adam Inglot
Faculty of Civil and Environmental Engineering
Gdansk University of Technology
Gdańsk, Poland
adam.inglot@pg.gda.pl

Paweł Tysiąc
Faculty of Civil and Environmental Engineering
Gdansk University of Technology
Gdańsk, Poland
pawel.tysiac@pg.gda.pl

Abstract

Laser scanning technology is a spatial information gathering technique which is commonly used all over the world. Systems where the red-light beam are used, are divided into: terrestrial, mobile and airborne scanning systems. The main differences between those are the accuracy, the data acquisition solution (f. e. in ALS and MLS besides of the laser scanner, the inertial navigation system is required) and the covered area in one mission campaign. In addition to a type of the project, the systems could be used and merge as one to create precise, accurate 3D point model of the terrain without any gaps. The data which are provided need up to date. In this paper, authors presented the solution of densing the point cloud from the ALS by the use of terrestrial laser scanning system and low-level aerial photogrammetry to reduce the total costs of filling ALS point cloud.

***Keywords* — remote sensing, geographic information systems, geodesy, terrain mapping.**

I. Introduction

Laser scanning technology is commonly used all over the world for the last decades. Through that time, the techniques of data acquisition by using red- light scanners developed into many forms. The one of the most popular methods is ALS (Airborne Laser Scanning). Based on the LiDAR data, a Digital Terrain Model is possible to create. The accuracy of obtained data was conducted by the Reutebuch researches [14]. In Poland, administrations ordered to create DTMs where the reference data was points, coming from Airborne Laser Scanning. Moreover, the technology of laser scanning platform paced on an aircraft is widely used in forest management [5, 12] or coastlines with additional using of MLS and TLS systems [1, 6, 16]. The laser scanning technology could be successfully used in city modelling [3, 17]. The market is interested in this type of projects and developed many algorithms helping with data processing [8]. To generate a model in CityGML standard there is a need to combine the point cloud from airborne laser scanning with mobile and terrestrial. This is the result of measurement characteristics of ALS where only the roofs are scanned. In this paper, the authors are presenting the solution to integrate the point cloud, obtained from ALS technology with data from terrestrial laser scanning and optical scanning. The main goal is to estimate the deviation between the integration of the point clouds, claim the usefulness of this process and select proper parameters of the point cloud for further processing. In this paper, authors want to show the possibility of combining terrestrial laser scanning and optical scanning with airborne laser scanning in case of ALS point cloud update. Also, we want to show a good alternative for ALS measurements which are very expensive and post processing of this data are difficult and time consuming.

The object of this study is located in Gdansk, University of Technology campus and represented by Audytorium Novum building. The campus is placed in the urbanize terrain, belong to the administration boundries of Gdansk Wrzeszcz, which characterizes with geographical coordinates $54°22'20''N$, $18°36'56''E$. The ALS data is coming from the ISOK project [10], terrestrial laser scanning was

Table 1: *UAV's classification in addition to its capacity.*

Category	Explanation	Constraint (capacity)
OM	Individual constructed, Low-budget platforms up to 5000 euros	capacity of the UAV, depends on the type of the construction
M	mini and micro UAV's	$< 5kg$
L	UAV's with big capacity	$> 5kg$

Table 2: *UAV's classification in addition to its navigation in real time.*

Navigation module	Without GPS/ INS	Without GPS/ INS	Without GPS/ INS
Coordinates estimation	post-processing	post-processing/ real time	post-processing/ real time
Navigation availability in real-time	0	+	++
Accuracy	low	medium	high
Category	OM	M and L	M and L

possible to perform thanks to Apeks company which provided the authors Riegl VZ-400 laser scanner. The optical scanning was based on the images, captured by a camera, placed on an UAV.

II. Source of data

A. Low-Level Aerial Photogrammetry

In the low-level aerial photogrammetry, the photogrammetry platform is placed on the UAV (unmanned aerial vehicle). The UAVs could be classify in addition to its construction features (a type of the propulsion or a type of the power supply), weight, range or a maximum ceiling. International Society for Photogrammetry and Remote Sensing does not present the classification of the UAV-s [7]. The existed one is presented in Table 1 and Table 2 proposed by the *Eisenbeiß* [2].

The OM category described individuals constructions while the M and the L category are presenting the platforms of minis and micros where capacity does not exceed 5 kg (M) and exceed 5 kg (L). Table II is presenting the additional classification based on the navigation elements. There is a possibility to distinguish the systems, not equipped with the GPS/INS system, equipped and provide with DGPS/INS system. It has to be mentioned GPS is one of the functioning systems and proper name should be GNSS, but GPS is generally used on the flight platforms.

In addition to usefulness of the UAVs systems in geodesy measurements, the classification could be performed based on the relation between the range and the accuracy of the measurements. Unmanned aerial vehicles with the small, digital camera provides the registration of the pointed area and indicate an orientation of the photographs during the aerotriangulation. Crucial is to detect blurred image [15].

The main advantage of the UAVs in comparison to the manned aircrafts is that UAVs could be used in high risk situation, not risking the health of the pilot. Moreover they have its usefulness in not available or urbanized areas. Disadvantages of the UAVs are capacity and range. Small ones have an opportunity to start with the weight up to 2 kg. Problems which bring using UAVs in photogrammetry and remote sensing are taking care of by the Unmanned Vehicle Systems for Mapping and Monitoring Applications. Before, the data acquisition it was crucial to prepare a proper flight plan in addition to equipment and environmental safety. The factors, which have the biggest influence on the mission was wind direction and insolation. Lack of the wind provide the authors stability of the device and insolation has its influence on the quality of the images. The other factor, significant in the context of safety is a start and landing place. The characteristics of landings are different for the different types of UAVs. The key to prepare the landing is the appearance of obstacles. Moreover it is crucial to have the possibility of monitor and interference during the data acquisition. That provides the GPS/INS system. The possibility to stop the mission in bad weather conditions could prevent a potential danger or a collision. In photogrammetry methods, the most important factors for the further processing are GSD (ground sample distance), longitudinal and transverse coverage. By the term of georeferencing the data we could understand the use of GNSS receiver with the points, measured by total station which all of them could create tie points which could be used for georeferencing process.

B. Airborne Laser Scanning

The idea of acquired the data from airborne laser scanning comes to a measure the distance between an aircraft and a measured object, realized by a rangefinder.

With the rangefinger, simultaneously the inertial nav-

Postprint of: Inglot A., Tysiąc P., Airborne Laser Scanning Point Cloud Update by Used of the Terrestrial Laser Scanning and the Low-Level Aerial Photogrammetry,
2017 Baltic Geodetic Congress (Geomatics) Gdansk University of Technology • 22-25 June 2017 • Poland • DOI: 10.1109/bgc.geomatics.2017.75

Fig. 1: *ALS data visualization.*

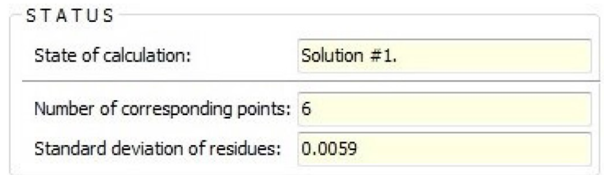

Fig. 2: *TLS data alignment with points, measured by the RTK method.*

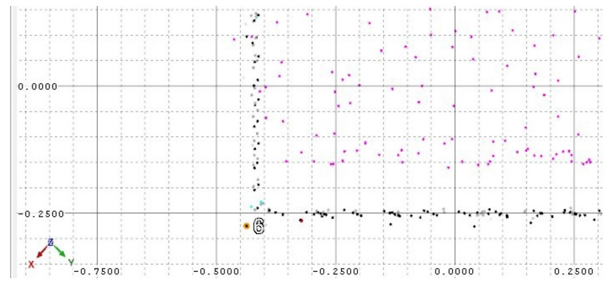

Fig. 3: *The horizontal difference between the TLS and Low- level aerial photogrammetry.*

igation system with GNSS are working. That combined components provide the whole information about a ground with assumed point density. In this papers, authors have data from ISOK [13] (IT system of the Country's Protection Against Extreme Harazds) project for Gdansk, Poland. Point cloud characterizes with 12 pts/m2 density [9, 10]. To maintain this value, the MPA (multiple pulses in the air) algorithm is crucial to use. The MPA technology is sending pulses, not waiting for previous one to register by a scanner. The example of ALS data is presenting in Fig. 1, where inside the red polygon is an area of study.

C. Terrestrial Laser Scanning

Terrestrial Laser Scanners provide detailed and highly accurate 3D data. Applications where could be used are wide ranging, including Architecture, Civil Engineering, Topography. The working idea is similar to airborne, because it comes to measure a distance between the instrument and the scanned object. Alignment of the scans comes to match them on points, indicate by the user and create planes where the center of gravity and normal vector for each one is estimated. The process is described in the integration of the data chapter and could be successfully used in case of scan data alignment between each other and merged point cloud with clouds from different platforms for example airborne laser scanning or low-level aerial photogrammetry.

III. Integration of the data

The integration of the data was performed in Riscan PRO software, provide by the ZUI Apeks company, based in Gdansk. The idea of such an operation could be realize in two different ways.

The first one is to georeference the data of three different types of measurements. It could be done by the GPS/INS system in airborne laser scanning, assisted with the planes (for example roofs of buildings), measured with traditional methods. With the information, provided by the Head Office of Geodesy and Cartography, the standard deviation of data alignment should not exceed 20 cm. In case of TLS measurements, 8 points were measured by use of the real time kinematic method and the alignment standard deviation between those points and the scanned ones, are presenting in Fig. 2. The used coordinate system was ETRS89 / Poland CS92.

The idea of merging the point clouds is to open them in a same view. The evaluation of data could be performed by measuring a distance between same points, representing ALS, TLS and low-level aerial photogrammetry. In the Fig. 3, the authors are presenting the mismatch. The black color represents the poins from the TLS, and fuchsia- from lowlevel aerial photogrammetry. With using GPS (in case of the TLS) and Total Station (in case of the low-level aerial photogrammetry) the horizontal difference between the same wall equals approximately 10 cm, because values which could be seen in Fig. 3 are in meters. The accuracy of a point model for ALS data update could be enough, but if we want to have more accurate model the alignment operation have to be performed.

The second method of data integration, which could be used not only to merge point clouds from different

Postprint of: Inglot A., Tysiąc P., Airborne Laser Scanning Point Cloud Update by Used of the Terrestrial Laser Scanning and the Low-Level Aerial Photogrammetry,
2017 Baltic Geodetic Congress (Geomatics) Gdansk University of Technology • 22-25 June 2017 • Poland • DOI: 10.1109/bgc.geomatics.2017.75

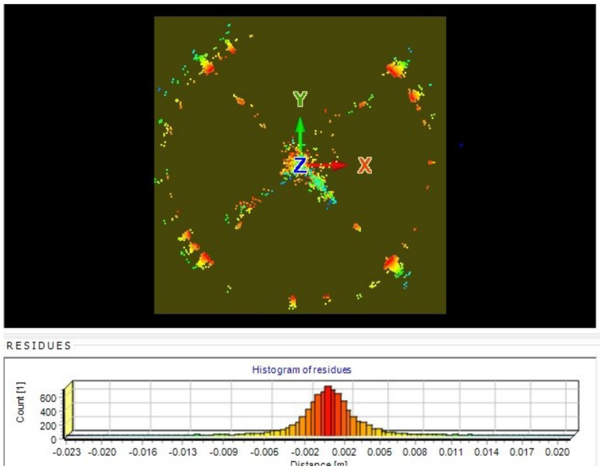

Fig. 4: *The histogram of data alignment.*

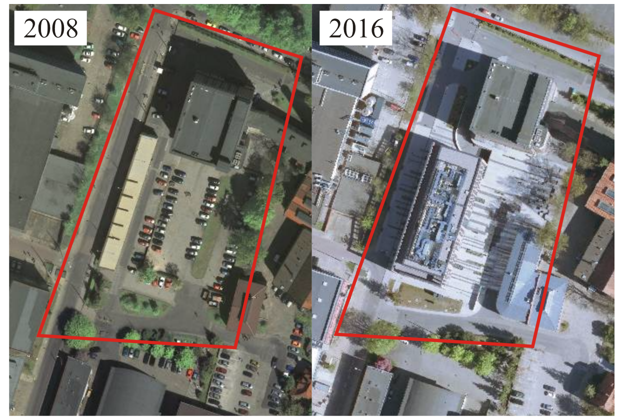

Fig. 5: *Changes in Gdansk University of Technology campus in studied area.*

platforms but also for scan positions comes to divided point clouds into cubes where the planes are searched. The user describe the maximum plane error and the minimum number of a plane point count. In addition there is an opportunity to create tie points which could be measured manually. That prepared data, the software aligned using least square method. Because the TLS data characterizes the highest accuracy, it could be used as the reference. The alignment between the whole data are presented below in Fig. 4. At the bottom of that figures the distance between the planes are shown and based on that data, the standard deviation could be estimate. The values are in meters.

It has to be mentioned that the data alignment, even where is not exceeded 1 cm is not reliable. For example the planes from different objects could be matched or the program align only those planes which belong to objects, in short distance from a scanner. The error growths with increasing a disstance between a device and scanned object. Before the conclusions, those situation has to be checked where the accuracy is crucial. To update the ALS point cloud, where the accuracy is the lowest there is no need to check such an issue.

In this paper, the data coming from the Main Office of the Geodetic and Cartographic Documentation Center was updated. Laser scanning points came from 27 and 28 june 2011 and saved as the 1.2 las files where the classification, according to ASPRS specification was performed. In Fig. 5, the authors shows the noticeable changes of the Gdansk University of Technology campus. The building, built in 2015 was not captured in ALS measurements, but it was inventoried during TLS and low-level aerial photogrammetry measurements.

Table 3: *Standard deviation in reference to type of terrain.*

Type of terrain	SD [m]
Ground	0.13
Vegetation	0.16
Building	0.04

Updating measurements was executed on the 21 september 2016 using UAV and on the 6 march 2017 in case of terrestrial laser scanning measurements. Close range photogrammetry measurements filled spatial information about roofs of the Audytorium Novum, when the terrestrial laser scanning updated ground and vegetation.

Table III is presenting the standard deviation in reference to type of terrain integration with ALS point cloud. The results of data integration is shown in Fig. 6 where the red colour is presenting the ALS points cloud and yellow- combined data from terrestrial laser scanning and low-level aerial photogrammetry. What is more, the vegetation integration deviation equals 0.16 meters and is connected with the noise, coming from the trees [4]. SD values estimation comes to check mean distances between matching planes described in chapter III. Moreover, points density on the roofs of the building equals 862 points per square meter and density of ground and walls equals 8042 points per square meter after update. It was dependent on the scan pattern resolution and aligned photographs.

IV. Conclusions

Airborne Laser Scanning is an effective tool for gathering spatial information about the terrain but still not very available and very expensive. For the processing purposes, not

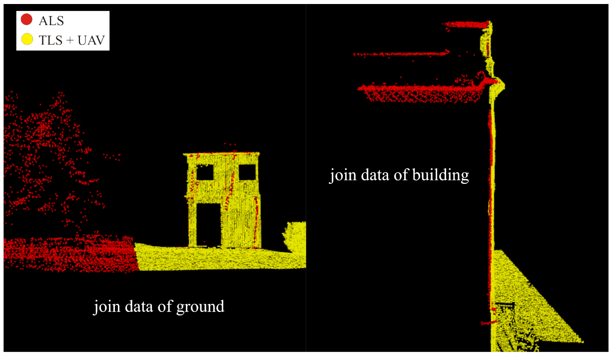

Fig. 6: *TLS+UAV data integration with ALS point cloud.*

covered by a lot of area there is a possibility to update ALS point cloud, do not spend money for another flight mission. In this article the authors presented use of UAV and terrestrial laser scanning to obtain the satisfactory results in reference to airborne laser scanning point cloud update for further processing. Moreover, the data, coming from the close range photogrammetry and the scanner, placed on a tripod characterize higher precision and accuracy in comparison to ALS [18]. The integration of the data is not a problem [1, 11, 19] and there is a possibility to do it in two ways. First is to georeference every of data, and another is to use plane patch filter algorithm to combine every of data, where one is the reference. Larger problem is the change of the terrain during time between the measurements. In case of our study the new construction was built which influence on the classification and the integration process.

References

[1] K. Bobkowska, A. Inglot, M. Mikusova, and P. Tysiąc. Implementation of spatial information for monitoring and analysis of the area around the port using laser scanning techniques. *POLISH MARITIME RESEARCH*, 24(93), 2017.

[2] H. Eisenbeiß. *UAV photogrammetry*. ETH Zurich, Switzerland, 2009.

[3] G. Forlani, C. Nardinocchi, M. Scaioni, and P. Zingaretti. Complete classification of raw LIDAR data and 3D reconstruction of buildings. *Pattern Analysis and Applications*, 8(4):357–374, feb 2006. ISSN 1433-7541. doi: 10.1007/s10044-005-0018-2.

[4] B. Hejmanowska and A. Warcho. Comparison of the Elevation Obtained from ALS, ADS40 Stereoscopic Measurements and GPS. *Acta Scientiarum Polonorum. Geodesia et Descriptio Terrarum*, 9(3):13–24, 2010.

[5] M. Holopainen, M. Vastaranta, V. Kankare, X. Liang, P. Litkey, H. Kaartinen, A. Kukko, A. Jaakkola, H. Hyyppä, and M. Vaaja. The use of ALS , TLS and VLS measurements in mapping and monitoring urban trees. In *Urban Remote Sensing Event (JURSE), 2011 Joint*, pages 29–32. Urban Remote Sensing Event (JURSE), 2011 Joint, 2011. ISBN 9781424486571.

[6] A. Janowski, J. Szulwic, P. Tysiąc, and A. Wojtowicz. Airborne And Mobile Laser Scanning In Measurements Of Sea Cliffs On The Southern Baltic. *Photogrammetry and Remote Sensing*, 2:17–24, 2013. doi: 10.5593/SGEM2015/B12/S2.003.

[7] M. Kędzierski, A. Fryśkowska, and D. Wierzbicki. *Opracowania fotogrametryczne z niskiego pułapu*. Wojskowa Akademia Techniczna, 2014.

[8] K. Kozioł and P. Wężyk. Aplication of Delaunay Algotithm in Elimination and Classification of point Clouds From Terrestrial Laser Scanning. *Annals of Geomatics*, 5(5):33–41, 2007.

[9] Z. Kurczyński and K. Bakuła. Generation of Country-wide Reference Digital Terrain Model from Airborne Laser Scannig in ISOK Project, 2013.

[10] M. Maślanka. Factors influencing ground point density from Airborne Laser Scanning - a case study with ISOK Project data. *Annals of Geomatics*, 14(4(47)):511–519, 2016.

[11] S. Mikrut, A. Moskal, and U. Marmol. Integration of Image and Laser Scanning Data Based on Selected Example. *Image Processing & Communications*, 19(2-3):37–44, 2014. ISSN 2300-8709. doi: 10.1515/ipc-2015-0008.

[12] E. NÆSSET, T. GOBAKKEN, J. HOLMGREN, H. HYYPPA, J. HYYPPA, M. MALTAMO, M. NILSSON, H. OLSSON, A. PERSSON, and U. SODERMAN. Laser Scanning of Forest Resources: The Nordic Experience. *Scandinavian Journal of Forest Research*, 19(6): 482–499, 2004.

[13] K. Pawłuszek, M. Ziaja, and A. Borkowski. Accuracy assessment of the height component of the airborne laser scanning data collected in the isok system for the widawa river valley. *Acta Sci Pol Geod Descr Terr*, 13(3-4):27–38, 2014.

[14] S. E. Reutebuch, R. J. McGaughey, H.-E. Andersen, and W. W. Carson. Accuracy of a high-resolution lidar terrain model under a conifer forest canopy. *Canadian journal of Remote Sensing*, 31(4):283–288, 2005. ISSN 1712-7971. doi: 10.5589/m05-016.

[15] T. Sieberth, R. Wackrow, and J. H. Chandler. Automatic detection of blurred images in UAV image sets. *ISPRS Journal of Photogrammetry and Remote Sensing*, 122:1–16, dec 2016. ISSN 09242716. doi: 10.1016/j.isprsjprs.2016.09.010.

[16] J. Szulwic, P. Burdziakowski, A. Janowski, M. Przyborski, P. Tysiąc, A. Wojtowicz, A. Kholodkov, K. Matysik, and M. Matysik. Maritime Laser Scanning as the Source for Spatial Data. *Polish Maritime Research*, 22(4):9–14, 2015. ISSN 20837429. doi: 10.1515/pomr-2015-0064.

[17] R. O. Tse, C. Gold, and D. Kidner. 3D City Modelling from LIDAR Data. In P. Van Oosterom, S. Zlatanova, F. Penninga, and E. M. Fendel, editors, *Advances in 3D Geoinformation Systems*, pages 161–175. Springer Berlin Heidelberg, 2008. doi: 10.1007/978-3-540-72135-2_10.

[18] J. Wang, L. Xu, X. Li, and Z. Quan. Quantitative Evaluation of Impacts of Random Errors on ALS Accuracy Using Multiple Linear Regression Method. *IEEE Transactions on Instrumentation and Measurement*, 61(8):2242–2252, aug 2012. ISSN 0018-9456. doi: 10.1109/TIM.2012.2184190.

[19] A. Warchoł and B. Hejmanowska. Example of the assessment of data integration accuracy on the base of airborne and terrestrial laser scanning. *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, 22(Miller 2008): 411–421, 2011.