COMPARISON OF AIRBORNE LASER SCANNING OF LOW AND HIGH ABOVE GROUND LEVEL FOR SELECTED INFRASTRUCTURE OBJECTS

J. Siwiec [a]

[a] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Engineering Surveying and Civil Engineering, al. Mickiewicza 30, 30-059 Kraków, Poland, e-mail: jsiwiec@agh.edu.pl

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ABSTRACT:

Along with the development of the technology of drone construction (UAV - Unmanned Aerial Vehicles), the number of applications of these solutions in the industry also grew. The aim of the research is to check the accuracy of data obtained using the new technology of UAV scanning and to compare them with one that is widely spread - high-altitude airborne Lidar, in terms of quality and spectrum of applications in industry and infrastructure. The research involved two infrastructure objects: a reinforced concrete one-span bridge and Lattice transmission tower with powerlines. The density of measurement, internal and external cohesion of point clouds obtained from both methods were compared. Plane fitting and deviation analysis were used. The data of UAV origin in both cases provided a sufficient density, allowing the recognition of structural elements, and internal coherence and precision of measurements important in modeling. The study shows that UAV mounted scanning may be used in the same applications as Airborne Lidar, as well as in other tasks requiring greater precision.

1. INTRODUCTION

Lidar - Light Detection and Ranging is mainly associated with airborne laser scanning. In contrast to terrestrial scanning, it enables coverage of large areas, including areas not available for measurement from the ground.

With the development of UAV technology, the number of applications of these solutions in industry grew. The popularity of photogrammetric systems based on non-metric digital cameras mounted on a multicopter or fixed-wing planes (Ham, Y., et al., 2016). These systems characteristic was a small mass of measuring equipment (cameras) and positioning systems operating in autonomous mode (GNSS solution). In order to process the measurement data, the use of GCP was also necessary. GCP - Ground Control Points are photo points, which ensure a proper spatial reference (external orientation of the created model) in the post processing (Colomina, I., & Molina, P., 2014). For technical reasons, airborne scanning was previously reserved for aircraft. It was caused by a large mass and size of scanners and devices necessary to determine the exact position of the measurement system in time and space, with parameters of the angular orientation of the system. In contrast to aerial photographs, scanning to maintain high measurement precision requires knowledge of the exact position and spatial orientation of the system. Images has the possibility to recalculate this position during aerial triangulation - using the points identified in different pictures as identical, which combine photos into a coherent model ensuring the orientation of photos between themselves, and ground-based points of known coordinates (AICARDI, I., et al., 2016).

The need to determine the exact position of the scanner during the measurement results from the characteristics of the mobile scanning, where each measured scan line must have a known spatial position - orientation along the trajectory (Kukko, A. et al., 2012). This is the main difference between mobile and terrestrial laser scanning (TLS). Principle of the TLS is stationary position of one setup – scan station. In the case of mobile scanning either ground based or airborne, the current accuracy of the position along trajectory is ensured by the integration of the RTK GNSS system and the IMU inertial unit (Brede, B., et al., 2017).

The main principle of this system is the combination of discrete observations with RTK GNSS - positions with observations of a stationary station receiver with known coordinates. The role of a base station can be fulfilled by a single GPS receiver or a network of reference stations. Positions between consecutive positions calculated from GNSS postprocessing are supplemented with observations from an inertial unit composed of a set of accelerometers. Thanks to the common alignment of observations, the internal precision of the trajectory geometry is improved, while the GNSS postprocessing ensures the accuracy of the global location at the level of single centimeters (Hutton, J., et al., 2007). The use of the INS-GPS RTK system enables measurement without the use of additional ground measurements (Mian, O., et al., 2015).

Miniaturization of these systems and the creation of light laser scanners, made it possible to install these devices on unmanned aerial systems, without compromising the accuracy of the result.

Instruments mounted on the UAV are characterized by lower signal power. As method remains unchanged, the scale and difference of distance to measured object makes it possible to obtain a result with greater precision and consistency.

The aim of the work was to compare the data obtained from two Lidar measurement methods - high and low above ground level scanning.

2. MATERIALS AND METHODS

The study was carried out on the example of two infrastructure facilities, transmission tower high voltage lines and a concrete bridge. For both of the studied areas, a point cloud obtained from the Lidar flight was obtained from the PZGiK (State Geodetic and Cartographic Resource) resource. It was measured within the ISOK project using the Riegl LMS-Q680i scanner with the following parameters, mounted on lightweight airplane (Figure 1):

Maximum rate of effective measurement is up to 266 kHz at scan angle of 60 degrees (-30°; +30°). Maximum range of measurement at signal frequency of 400 kHz spans from 1000m – 1600m depending from reflectivity of the material. Angular step – resolution between measurements is 0.002°. Laser Beam Divergence – angular measure of the radius of the beam footprint increase is less than 0.5mrad, which means that in the distance of 1000m laser beam footprint would reach approximately 500mm diameter. Scanner allows for measure unlimited number of targets (echoes) (Riegl, 2012). It is usually mounted on light aircrafts with typical above ground level between 900 and 1000 m.

The same objects were also subjects of scanning measurements that were performed using multicopter Riegl Ricopter (Figure 1) with the VUX-1 scanner. It is a fully integrated measuring system that is a miniature of Lidar aircraft systems.

Maximum Take-off Mass of the integrated system is 25 kg and contains both UAV platform and scanner with equipment. The scanner is equipped with a near infrared laser, operating at a frequency of up to 550 kHz, at which the maximum effective range is from 170-300 m. The minimum angular step between laser shots is 0.006°. The divergence of the laser beam is maintained at less than 0.5 mrad - the same as in the LMS-Q680i scanner, which means that within the effective measurement range of 100 m the diameter of the laser spot is 50 mm. VUX-1 also supports echo measurement. The effective angle range of the measurement includes a spectrum of 330 degrees, 165° in each side (Riegl, 2017). The blind field only includes the construction of the UAV platform. The typical altitude above ground level usually does not exceed 150 m.

Scanner is integrated with inertial unit INS/GNSS Applanix AP20, that assure accuracy of position of 0.05m horizontally and 0.10 m vertically.

Figure 1. UAV Riegl RiCopter (left) and plane Cessna T206H (right)

3. CASE 1 – CONCRETE BRIDGE

Bridges, like other infrastructure objects, require monitoring and regular measurement. New Non-Destructive Testing methods join widely used visual methods. These NDT methods include laser terrestrial scanning and photogrammetric methods (Valença, J., et al., 2017). TLS offers dense and precise measurement, but in many cases, with more complex structure and geometry, it lacks the field of view and may be insufficient to cover inaccessible, obscured parts (Bolourian, N., et al., 2017). The use of UAV, both photographic and equipped with a laser scanner can help overcome these defects (Rau, J. Y., et al., 2017). In the case of such a measurement, it is necessary to carefully plan the tests, the device parameters and the path of the drone flight (Bolourian, N., et al., 2017).

The case of a bridge measurement became an opportunity to compare the quality and density of data generated from air scanning of low and high AGL (Figure 2 and 3). Data from Airborne Lidar cannot be used for detailed examination of the object's condition, but it should be sufficient to determine the situational and altitude location of some of its elements, such as roads or barriers (Yen, Kin S., et al., 2011).

Both data from the Airborne Lidar and UAV flight were not adapted specifically to the characteristics of the object. Lidar data came from the public resource, while the UAV flightplan was adapted rather to surface measurements, often used to create a Digital Terrain Model.

Figure 2. Isometric view of the bridge – UAV point cloud

Figure 3. Isometric view of the bridge – Lidar point cloud

3.1 Parameters of Lidar and UAV gathered data

The Airborne Lidar mission was planned as a block of parallel scanning lines. The average AGL was 980 m, and the distance of the scanning line from each other was not to exceed 560 m. The signal emission frequency was 360 kHz, which resulted in an effective scanning frequency of 180 kHz. To obtain the minimum planned value of the density of the point clouds, 4.3 pts/m^2, the speed was set at 50 km/h. According to State Resource documentation, the resultant point cloud belonged to category I and its mean altitude error may be 0.20 m.

The UAV flight was realized at 140 m AGL, with a cruising speed of 10 m/s. The measuring block consisted of parallel scanlines, which axes were 130 m apart from each other, which made it possible to provide sidelap of scans at 50%. For aerial scanning from UAV, 90° (-45°, +45°) are considered for coverage, and the recording range has been extended to 120 degrees (-60°, + 60°)

Measured object was single span concrete beam bridge. Its 50 m span was situated 10 m above water surface. Cross-section of the road surface was two sided slope.

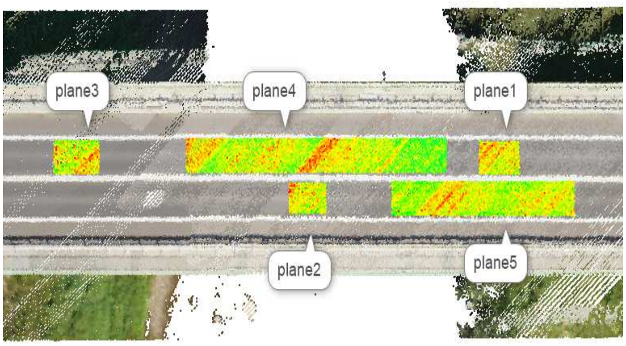

Figure 4. Location of the test fields

3.2 Analysis:

On the surface of the object, five test fields in the shape of rectangles were selected: three with dimensions similar to 4.5x2.5 m and two additional covering larger area (Figure 4). In order that these fields covered only planar surface of the bridge without other objects, they were situated on the one half of the roadway and covered only a section of asphalt. Then, corresponding fragments of point clouds (Lidar and UAV) were cut out in each field. A regression plane is fitted in each slice. Planar fit statistics can be found in the tables below (Table1, 2, 3, 4, 5, 6, 7).

The Figure 4 shows the distribution of test fields on the bridge's roadway.

Table 1. Fitting statistics of regression plane 1

Plane1	Dimensions: 4.43 x 2.28 m		Area: 10.10 m^2		
	Number of points	Density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	175	17.3	0.107	0.025	0.018
UAV:	2733	270.6	0.038	0.006	0.014

Table 2. Fitting statistics of regression plane 2

Plane2	Dimensions: 4.11 x 2.68 m		Area: 11.02 m^2		
	Number of points	Density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	152	13.8	0.066	0.027	0.022
UAV:	1898	172.3	0.046	0.007	0.016

Table 3. Fitting statistics of regression plane 3

Plane3	Dimensions: 5.14 x 3.20 m		Area: 16.45 m^2		
	Number of points	Density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	187	11.4	0.078	0.021	0.024
UAV:	1456	88.5	0.041	0.004	0.012

Table 4. Summary of regression statistics (planes 1, 2, 3)

	Mean density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	13.7	0.107	0.024	0.021
UAV:	162.0	0.046	0.006	0.014

Table 5. Fitting statistics of regression plane 4

Plane4	Dimensions: 28.64 x 3.17 m		Area: 90.79 m^2		
	Number of points	Density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	1207	13.3	0.226	0.055	0.097
UAV:	11618	128.0	0.226	0.011	0.049

Table 6. Fitting statistics of regression plane 5

Plane5	Dimensions: 20.08 x 3.03 m		Area: 60.84 m^2		
	Number of points	Density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	656	10.8	0.158	0.036	0.067
UAV:	10023	164.7	0.158	0.016	0.048

Table 7. Summary of regression statistics (planes 4, 5)

	Mean density (pt/m^2)	Max dist. (m)	Avg. dist. (m)	Sigma (m)
Lidar:	12.3	0.226	0.046	0.082
UAV:	142.7	0.226	0.014	0.049

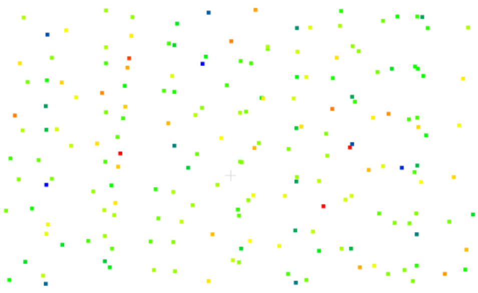

Figure 5. Map of deviations – Lidar point cloud

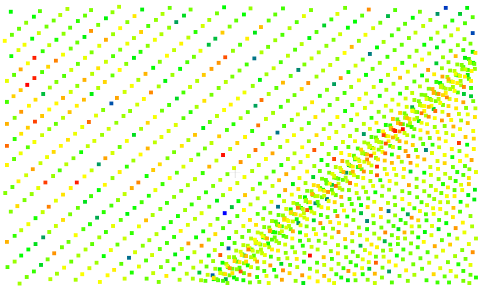

Figure 6. Map of deviations – UAV point cloud

Tables 4 and 7 contain average values for test fields, respectively small and large.An analysis of point cloud distances to fitted plane was carried out using method Cloud to Mesh (C2M). The results were diagrams of point's distances from surfaces (Figure 5, 6). Histograms (Figure 7,8) presenting point deviations from plane 3 show, that distribution of deviations is random and even in both cases. The obtained mean values of deviations for the UAV method are twice smaller than those obtained from airborne Lidar. The density of the Lidar cloud is four times higher than planned (4.3 pt/m^2), this is due to good exposure and lack of obscuration. The results indicate that in the case of larger fields, the values of the maximum deviations are almost equal, however, the proportion of mean distance values and their standard deviations is maintained.

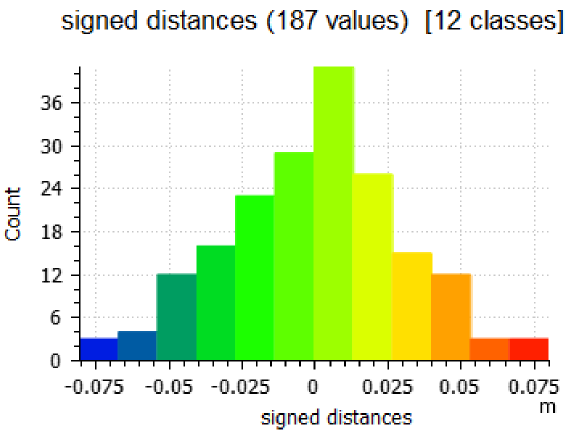

Figure 7. Histogram of deviations from plane3- Lidar

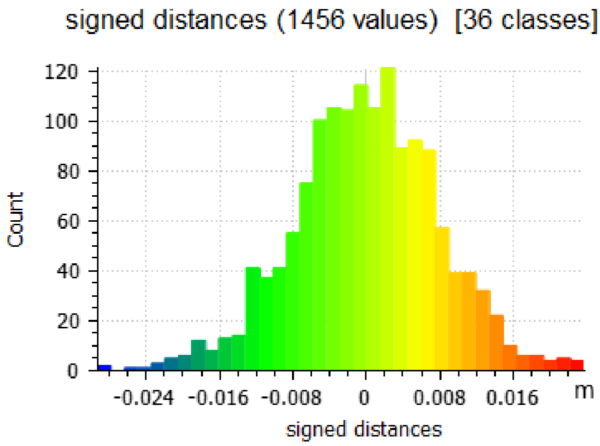

Figure 8. Histogram of deviations from plane3- UAV

Another analysis was the creation of a cross-section through the bridge span. (Figure 9, 10, 11) A cross-section of a point clouds of 10 cm thickness shows the difference in density of the object's coverage. It is possible to observe the elevation difference between the cloud obtained from UAV and Airborne Lidar that is on average 11 ±3cm (Figure 11).

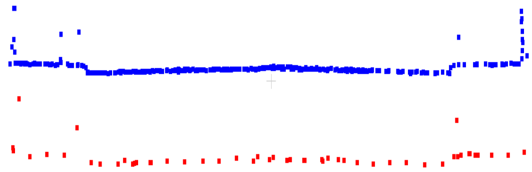

Figure 9. Cross-section of bridge span from UAV (upper). Cross-section of bridge span from Lidar (lower)

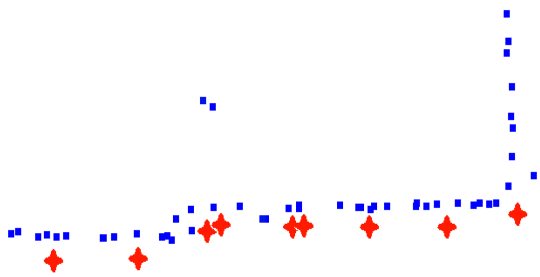

Figure 10. UAV and Lidar clouds cross-section close-up (crosses – Lidar, points – UAV)

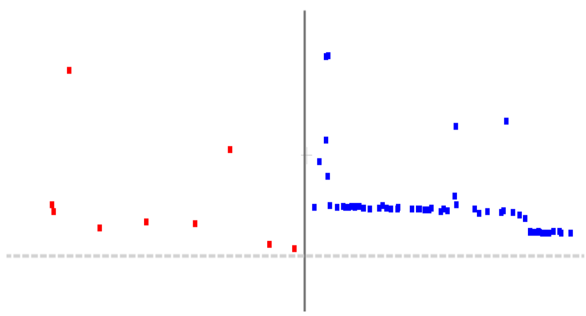

Figure 11. Cross section – barrier, pavement, curb (left – Lidar, right – UAV)

3.3 Conclusions

The result of the conducted analyzes confirms the advantages of using UAV mounted Lidar. On a small scale of individual objects such as bridges, a low altitude airborne laser scanning can provide a dense coverage of the object even if it was within a range of one scan line. It can be noticed by observing the pattern created by the point cloud on the surface of the object. The pattern depends on the path of the flight and the instantaneous velocity of the UAV relative to the ground. The cloud obtained by this method is uniform and clearly coherent. Values of both mean distance of point cloud to regression plane and its standard deviation is two times lower. The quality of the data enables surface modeling and recognition of construction details, such as curbs, barriers and handrails, or when recognizing horizontal markings.

The better results in case of point cloud density and precision of reproduction of the objects still can be obtained. This requires designing a measurement to match the tested object, which is allowed by the characteristics of the UAV measurement.

4. CASE 2 – LATTICE TRANSMISSION TOWER

The main reason of taking measurements of transmission towers is need of regular, periodic monitoring. The methods, that are well established in monitoring and measuring of transmission towers and powerlines corridors comprises terrestrial field survey and aerial mapping. These methods evolved from teams of engineers performing checking of foot or from helicopters (that methods are still in use). Both methods had theirs pros and cons. Monitoring from ground was laborious but was not restricting time of inspection, whereas helicopter inspection was more efficient, but it was limiting observation time. Nowadays these visual based methods are more and more often replaced by mapping technology. This solution allowed to gather data on site and analyse it later. We are able to distinguish several methods of measurements: ground based survey, terrestrial laser scanning and aerial methods that include photogrammetric approach and Lidar. Today use of UAV carrying photographic cameras have become popular in monitoring power lines (Matikainen, L., et al., 2016; Moore, A.J., et al., 2017; Jiang, S., et al., 2017).

Just as in the case of mentioned visual methods, general rule remains the same. Ground based methods can be precise but require high effort and are time consuming. On the other hand, traditional aerial measurement is more efficient in terms of mapped area, but cannot be as adapted to object as terrestrial measurements. Due to high cost of single measurement, airborne missions have to be designed on bigger areas to make it profitable.

Study of Teng, G. E., et al., 2017 presents application of UAV based mini Lidar in inspection of high voltage lines in inaccessible terrain, where other methods are not efficient or profitable.

This part of the paper focuses on use of airborne Lidar in power lines monitoring. To compare data from plane and UAV Lidar two point clouds of the same object were gathered.

4.1 Parameters of Lidar and UAV gathered data

Metadata of Lidar origin point cloud describes typical values of parameters of flight. Planes maximum velocity during scanning should not exceed 40 m/s. Pattern of flight was set of parallel scanlines 640 m apart from each other on 850m AGL.

UAV measurements was planned as grid pattern of lines 80 m apart from each other on 70 m AGL. The condition of sidelap coverage of scans at the level of approx. 50% has been preserved - the data acquisition region of 120 degrees was used, as in the case of the bridge measurements in case 1. The planned cruising speed was 10 m/s.

Measured object was the first tower from electrical substation. Its height was 32m and 11m span of its cross arms. Horizontal distance to the nearest tower, and span of the powerlines was 120m.

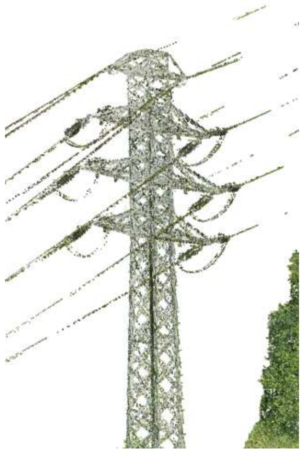

Figure 12. Isometric view of transmission tower – UAV

Figure 13. Isometric view of transmission tower – Lidar

(Figure 12) and (Figure 13) show the identical elements from measurement in two methods, respectively high and low AGL scanning, depicting difference in density of point clouds. On the orthogonal view of the transmission tower (Figure 14) difference in captured detail can be noticed. The cloud from Lidar allows the location of the structure and surroundings (Kwoczyńska, B.; Dobek, J., 2016), and can also be used to measure cables (deflection measurement) (Matikainen, L., et al., 2016). In addition to the observed higher density of clouds on the ground surface, the UAV cloud provides higher spatial resolution on the object, where individual elements can be distinguished.

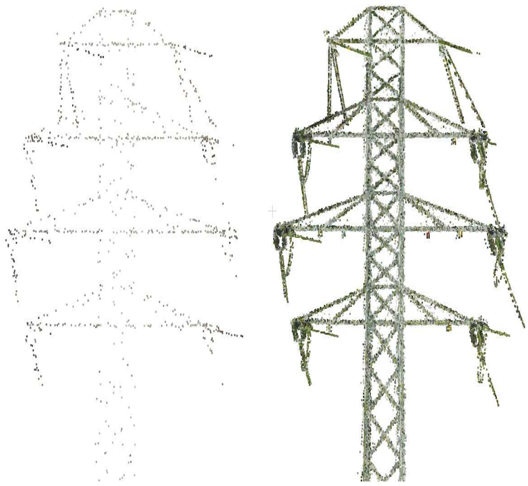

Figure 14. Orthogonal view of the transmission tower
(Left – Lidar, Right – UAV)

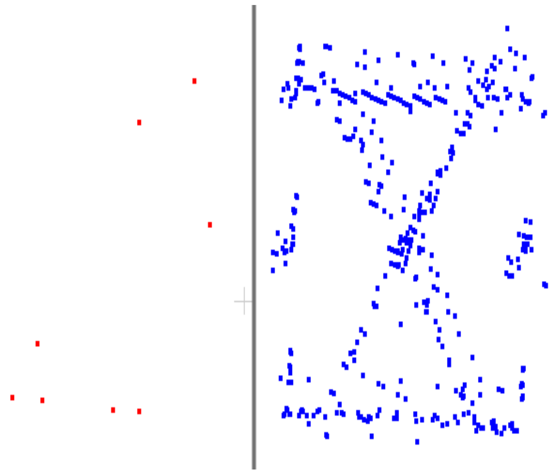

Figure 15. Horizontal cross-section of the truss
(Left – Lidar, Right – UAV)

Point clouds from Lidar and UAV were cut with a horizontal section with a thickness of 20 cm. The resulting cross-sections are shown in Figure 15. The cross-section from the UAV was 420 points, and from Lidar, 8 points. The difference in density was caused with geometry of the UAV flight, allowing measurements from different sides and angles. The Lidar point cloud does not give the possibility to recognize elements in this case. In UAV cloud distinctly recognizable are typical elements of the structure: wires, insulators and the construction of the tower, truss of individual beams. (Figure 15) shows point cloud classified manually based on the visual recognition.

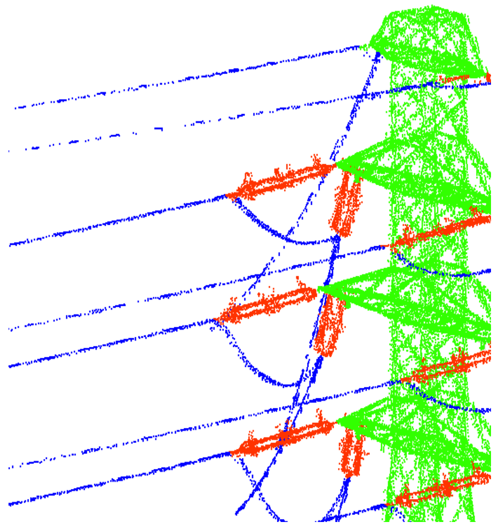

Figure 16. Classification of the structural elements on UAV point cloud (conductors, isolators, truss)

4.2 Conclusions

The quality parameters of point clouds obtained from both methods indicate the difference in possible applications of measurement methods. The key is to adjust the method and choose the right one for the intended purpose.

Airborne Lidar is characterized by high efficiency, it is performed for large areas, e.g. entire administrative units. It is possible to plan mission adapted not only to surface measurements, but also corridors (roads, transmission network) (Yen, Kin S., et al., 2011). This is related to the typical parameters of the aircraft - high speed, high altitude and considerable range. The disadvantage of this solution, in addition to high take-off costs and reaching the measurement location, is the lower limit altitude, which is a cause of the limitation of the accuracy and density of the scan. The minimum altitude is limited due to the terrain denivelations, economic considerations and aviation law.

The use of UAV to carry the laser scanner brings the airborne scanning features to terrestrial scanning. It combines the field of view of aerial measurements with measurements at a closer distance. This technology also has some limitations. It allows you to adapt the survey to a specific object, but a short flight time forces planning of multiple starts for larger objects. In the case of UAV scanning there is an opposite limitation to airborne Lidar - UAV cannot rise too high to reduce the point cloud density in order to cover a larger area with single scan. This is the result of both the construction characteristics - range and flight time, vulnerability to harsher atmospheric conditions at a higher level, and legal restrictions - in Poland unmanned flights are limited to 150 m above the ground surface. However, with less effort than with terrestrial scanning, it is possible to quickly obtain a dense, internally consistent point cloud, suitable, for example, for periodic monitoring of the condition of the structures under examination.

5. DISCUSSION

The study involved data obtained using the same measurement technology, made by the same manufacturer. The Mobile Scanning System - mounted on the UAV platform is a miniature of systems mounted on manned aircraft. Apart from their size, the geometry of the measurement also differs. Field of view of the airborne Lidar covers only small angle range and it is pointed directly downwards, whereas UAV mounted Lidar can take measurements of objects theoretically located above the scanner, which allow it to measure objects restricted from other methods. The scale of the measurement, focused on single or grouped objects at a short distance, allows adjusting the plan of the flight to best match the examined object.

Many factors influence the final measurement accuracy. Trajectory and positioning errors, scanning errors - angle and distance measurements. The difference in distance and range at which the measurement is performed (about 5-10 times smaller distance in the case of UAV) affects both the values of the errors transmitted on objects surface and the spatial resolution defined by the size of the laser beam footprint.

6. CONCLUSIONS

Low altitude scanners are miniaturised airborne equipment. They have some lower parameters of range and power than their counterparts. Despite this, due to closer location of measured objects and better suited geometry of measurement and smaller beam footprint it can provide data of higher density, bigger spatial resolution and greater consistency of point cloud. This method combines some advantages of aerial and terrestrial laser scanning: unrivalled field of view with precision and versatility, mobility.

These features make this method proficient for use in mapping and inspection of infrastructure objects.

7. ACKNOWLEDGEMENTS AND APPENDIX

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