Comparison of DJI Zenmuse L1 and RIEGL miniVUX-3UAV Data for DTM Generation in the Forestry Area for Archaeological Purposes

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ABSTRACT:
Lately, more and more laser scanners on UAVs have been launched to the market. In the literature, research can be found in which the point cloud accuracy, completeness as well as reliability of object 3D reconstruction on the point clouds from different laser scanners is described. However, there are also applications which do not require high accuracy, for example, the Digital Terrain Model (DTM) for forestry areas. In this article, the results of the experiment are presented in which DTMs generated for forestry from point clouds from two different UAV laser scanners were compared. The laser scanners that were compared were DJI Zenmuse L1 and Riegl miniVUX-3UAV. The point clouds were post-processed, and classification was carried out. After automatic classification, manual corrections were conducted based on the cross sections through the point cloud. Finally, DTMs and their derivatives were generated and compared. The results showed that the DTMs from UAV laser scanners provided more detailed ground information which enables deeper archaeological analysis.

KEY WORDS: LiDAR, ULS, UAV, archaeology, DTM

1. INTRODUCTION

Last years more and more laser scanners on UAVs have been launched to the market by different companies. The difference in price between available LiDAR sensors is noticeable, thus some analysis in the literature can be found, in which the point cloud accuracy, completeness as well as the reliability of object 3D reconstruction is willingly described. In Mandlburger et al. (2023), the differences between the DJI Zenmuse L1 and Riegl VUX-1UAV, laser scanners are presented, e.g. in the case of saddle roof and power line reconstruction. This research shows the differences between the data in geometry, which can be important for many applications that require high data accuracy, precision, and completeness. However, there are also applications that do not require such high accuracy. Such an example is terrain modelling and the generation of Digital Terrain Models (DTM). Using UAVs equipped with laser scanners for UAV-borne laser scanning (ULS) and later DTM generation is especially substantial in the forestry areas because the LIDAR vegetation penetration possibilities, compared to the point cloud from the UAV images, are greater.

Aerial laser scanning has been used for years in archaeology for archaeological prospection (Doneus et al., 2008) in forested areas, and the LIDAR technique is now widely accepted as the most effective for exploring forested areas in this type of application (Campana, 2017). ULS as a remote technique is also important for not easily accessible sites (Balsi et al., 2021). Therefore, the use of ULS for mapping archaeological sites seems to be an obvious application of this technology and a good test field for hardware comparison, especially since archaeological use of lidar for ground modelling may require a more detailed approach than is generally the case due to archaeologists' interest in more detailed DTM often representing small features or microtopography. However, filtering ground points in the dense UAV laser point cloud for archaeological purposes can be a problematic task. Different types and parameters of ground filtering can be applied. Storch et al. (2022) analysed different flight heights and speeds and also ground filtering methods for different test areas. Masini et al. (2022) concluded the research that tree cover and slopes make the reconnaissance of archaeological remains very difficult. Apart from DTM generation methods and point cloud filtering, important stage is DTM interpretation. For this purpose, different visualization methods can be applied (Roman et al., 2015).

The aim of the experiments presented in this paper was to compare the DTMs generated for forestry area from point clouds from two different UAV laser scanners. Additionally, the area had to possess distinctive and lasting terrain features. The chosen location was a hill south of Tarnów, situated between Dąbrówka Szczepanowska and Lubcza. Today, it is the site of war cemetery No. 193, where 594 soldiers from the Austro-Hungarian and Russian armies who fell in the battle for the hill are buried in two separate sections. Around the cemetery whole section of the frontline was preserved, containing parts of the trenches, dugouts and artillery shell craters (Fig. 1). The preserved landscape of the battlefield was to become, together with the cemetery, a memorial park but, after the end of WW2, the land was given to State Forests National Forest Holding and its original function has been forgotten.

2. STUDY AREA

In military terminology, the peak where we conducted our research is referred to as “Hill 419”. It was occupied by Tsarist (Russian Imperial) forces and heavily fortified. The first attempt to capture the hill was undertaken by Austro-Hungarian forces in the second half of February 1915. The 2nd Regiment of the Tyrolean Kaiserjäger was assigned the task. The assault began on February 18. At 6:00 a.m., the units moved toward the enemy’s position. A flanking attack was to be carried out by two groups led by Majors Psenner and Wied. By the end of the day, the troops had reached their assault positions and were conducting reconnaissance of the area ahead. Artillery fire intensified during the night. At the same time, sapper units attempted to destroy the barbed wire obstacles stretched in front of the hill’s defenders. The order to attack was given at 11:25, and at 13:50, after destroying the last wire barriers, the 2nd Tyrolean Kaiserjäger Regiment launched an assault on the enemy position at the top of

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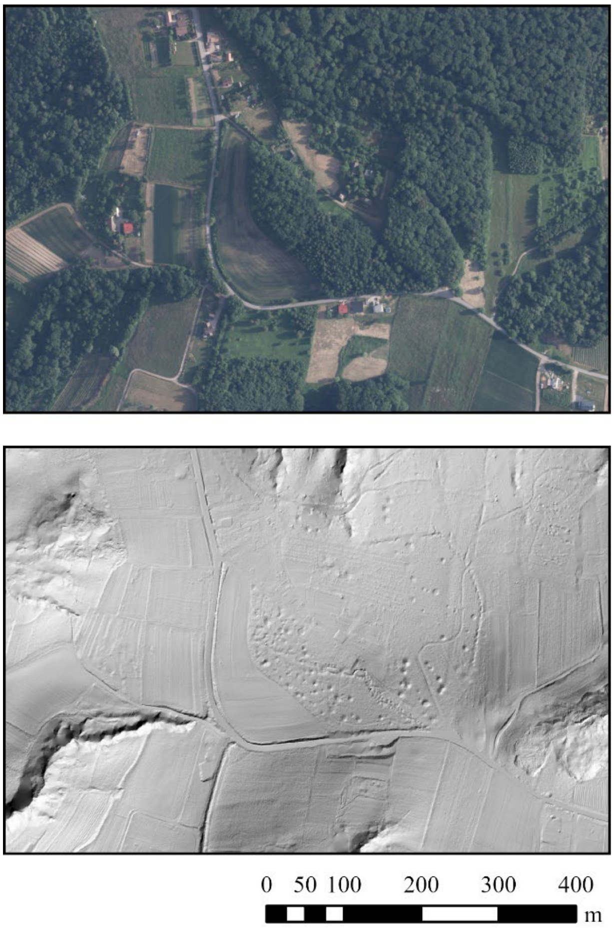


Figure 1. Aerial orthophoto map and shaded DTM of the test site: the Hill 419 between Dąbrówka Szczepanowska and Lubcza villages. Around the war cemetery for soldiers who fell in the battle for the hill in 1915, a whole section of the frontline was preserved, containing parts of the trenches, dugouts and artillery shell craters.

Hill 419. As we learn from the summary report, the assault stalled approximately 40 meters from the Russian positions, although some of the attacking soldiers managed to enter the enemy trenches. Fighting continued until about 4:00 p.m., after which the attackers were forced to withdraw to their original positions. That night, an order was issued to retreat from Hill 419. During the two days of fighting near Dąbrówka Szczepanowska, the 2nd TJR lost 3 officers and 61 soldiers killed, 10 officers and 342 soldiers wounded, and 68 missing. It was assumed that most of the missing had likely been killed or seriously wounded and left in no man's land, thus losing contact with the attacking units after withdrawal.

Less than three months later, the assault was repeated. The fighting that reignited near Dąbrówka Szczepanowska was part of the Central Powers' offensive, known as the Gorlice–Tarnów Offensive. This time, additional artillery support was assembled to weaken the enemy. The task of capturing Hill 419 was entrusted to the 4th Regiment of the Tyrolean Kaiserjäger. The units were deployed and concentrated in the combat area as early as April 30. On the morning of that day, the officers of the 4th TJR held a briefing and discussed operational plans. At the same time, the units conducted reconnaissance of the enemy positions to prepare for the attack. A strong enemy grouping was discovered to the southwest of the summit. Reconnaissance was conducted in combat — patrols were sent forward, engaged in firefights, and then withdrew. As in February, the attack was planned to be executed from the flanks. Full-scale combat broke out on May 2, when the units of the 4th TJR launched the assault at dawn. After initial successes, the enemy attempted to counterattack but failed to push the Tyrolean troops back. Russian Imperial forces continued to resist despite their positions being completely destroyed by artillery. Ultimately, the position on Hill 419 was captured by soldiers of the 4th TJR in the afternoon of May 3. Fighting between May 1–10, which peaked in intensity during the first days of the month, resulted in the deaths of 3 officers, 4 non-commissioned officers, and 186 soldiers, 18 officers, 17 NCOs, and 743 soldiers were wounded, 365 soldiers went missing, and 1 officer and 11 enemy soldiers were taken prisoner.

The comparative experiment described here was part of broader research in the field of conflict archaeology. During the study, it was determined that the hill was shelled by the heaviest artillery available to the Austro-Hungarian forces—namely, the 42 cm Küstenhaubitze M.14 and the famous "Slim Emma" 305 mm mortars, produced by the Skoda factory. Thanks to the application of scanning techniques, craters created by the shelling with these types of artillery were identified, while field studies confirmed use of such artillery, as fragments of 420 mm and 305 mm shells were discovered.

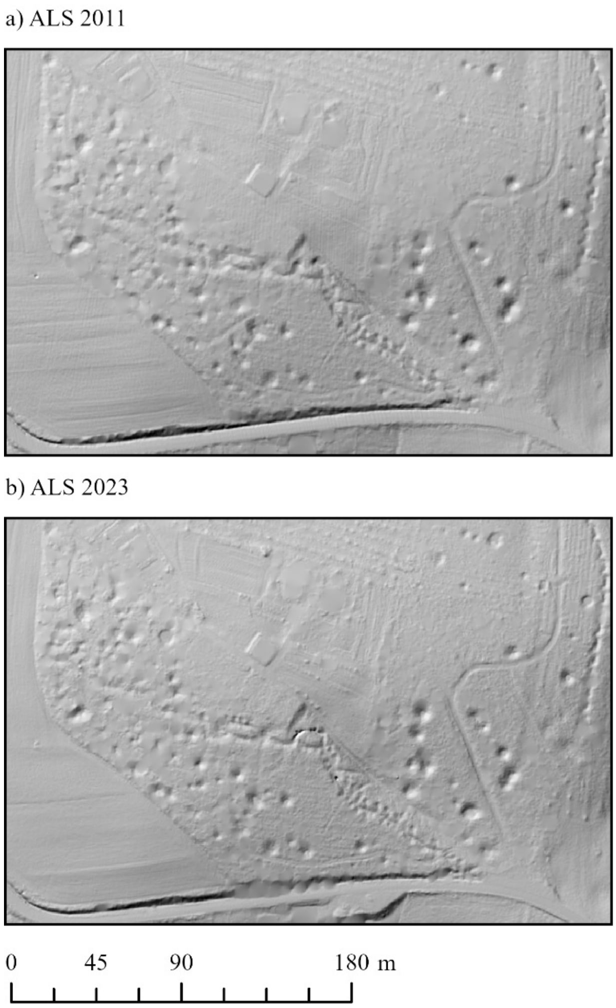


Figure 2. Shaded DTMs generated from ALS data (from 2011 and 2023) available for the test site in the data repository

For the selected test site, to collections of ALS data are available in the national data repository (Head Office of Geodesy and Cartography), which were acquired in different years (2011 and 2013). The quality of the ALS data (acquired for general purposes – not for archaeological studies) is unsatisfactory for archaeological studies not only because of the low density of the data (4 pts/m2) but also because of the clearly visible (Fig. 2) problem with penetration and unfavored filed conditions most of the artillery shell craters ware filled by water during ALS data collection.

3. METHODOLOGY AND DATA

The study was conducted using two laser scanners mounted on UAV. The first laser scanner is the DJI Zenmuse L1, and the second: Riegl miniVUX-3UAV. Both sensors were mounted on DJI Matrice 300 RTK UAV. Flights were conducted in a forestry area, over War Cemetery Dąbrówka Szepanowska near Tarnów, Poland.

The flights were conducted on 22 March 2024 during leaf-off period (Fig. 3). The flight speed was 5 m/s for both laser scanners. The overlap between neighbouring flightlines was between 60 and 70% to enable higher penetration and ground point density. The flight height was 50 m above ground level (AGL).

The data from miniVUX-3UAV was processed in POSPac UAV and RiProcess. Additionally, point cloud classification was performed in TerraScan. The data from DJI Zenmuse L1 was processed in the DJI Terra Pro software, and ground classification was also conducted in DJI Terra Pro software. The results of automatic classification were manually verified for both software packages. Concerning the DJI L1 flights, two flights were conducted using different scanning patterns (repetitive and non-repetitive) to examine whether there would be any difference in vegetation penetration and, thus, DTM quality.

Figure 3. Site during leaf-off period on 22 March 2024

Laser scanners used in the experiment are slightly different, taking into account the terrain size of the laser beam (footprint), as well as other parameters (Tab. 1). According to the Riegl mini-VUX-3UAV specification, the laser beam footprint size is 16 x 5 cm from 100 m AGL (Above Ground Level, riegl.com). For DJI Zenmuse L1, there is no official information about the footprint size available. For the newer version of the DJI laser scanner, Zenmuse L2, information is provided that the footprint size is 12x4 cm from 100 m AGL, which is said to be a fifth of the Zenmuse L1 footprint. Thus, it can be concluded that the Zenmuse L1 footprint size could be approx. 60x20 cm from 100 m AGL. The footprint size mostly influences the 3d reconstruction of the objects and point cloud noise, but it is worth discussing if the footprint size also influences the archaeological objects analysis.

Scanner	miniVUX-3UAV	Zenmuse L1
Type	Line (rot. mirror)	Risley prism
Scan angle	360	70.4
Scan frequency	max 200 000 pts/s	max 480 000 pts/s
Number of echoes	5	3
Range (80% reflectivity)	330 m	450 m
Accuracy	1,5 cm (50m AGL)	3 cm (100 m AGL)
Footprint (AGL 100 m)	16 cm x 5 cm	60 cm x 20 cm

Table 1. Comparison of the main parameters of both UAV laser scanners used in experiments.

It is justified to perform a comparison of the laser scanners, taking into account the difference in price. Additionally, cross sections through the point cloud were compared to analyse the penetration possibilities of the sensors.

4. RESULTS

In the beginning, the point density was analysed (Fig 4, Fig. 5). The median density of all points from Riegl miniVUX-3UAV scanner was 523 pts/m^2 and points on the ground: 166 pts/m^2. For L1 laser scanner and the non-repetitive pattern, the point density was 1 785 pts/m^2 and points on the ground: 611 pts/m^2. For the repetitive pattern, the point density was 1 141 pts/m^2 and points on the ground: 370 pts/m^2. The density of DJI L1 point clouds is much higher than Riegl data. However, in case of L1 scanner, on the beginnings and endings of each flight line, the scanner is performing calibration during the flight, when the speed is lower, thus the density locally is higher than in the middle of scanned area.

Another think that can be noticed analysing Fig. 5 is difference in point density on the ground. For non-repetitive scanning pattern, there are more points on the ground than for repetitive. For non-repetitive, there are about 200 up to 500 points per m^2, which is the highest number for examined 3 datasets. For Riegl point cloud the density is between 50 up to 200 points per m^2. The lowest number of the ground points is for repetitive scanning pattern in DJI L1 scanner: up to 150 points per m^2, but there are also quite many areas without any points and density lower than 50 points per m^2 as well as "no data" areas (black on Fig. 5).

In order to compare the DTMs from two laser scanners, the shaded DTMs were generated and compared with the DTMs generated from ALS point clouds available in the Polish repository. Mean density of the ALS point cloud is 4 pts/m^2, and the data was acquired on 30.10.2011 and 05.05.2023, so in full vegetation season (Fig. 2). The resolution of the DTMs from ALS point clouds was 0.5 m. Concerning the data repository, the openness and data availability are favourable, however the point density is very low, and the data are acquired rarely, in a time independent of a user.

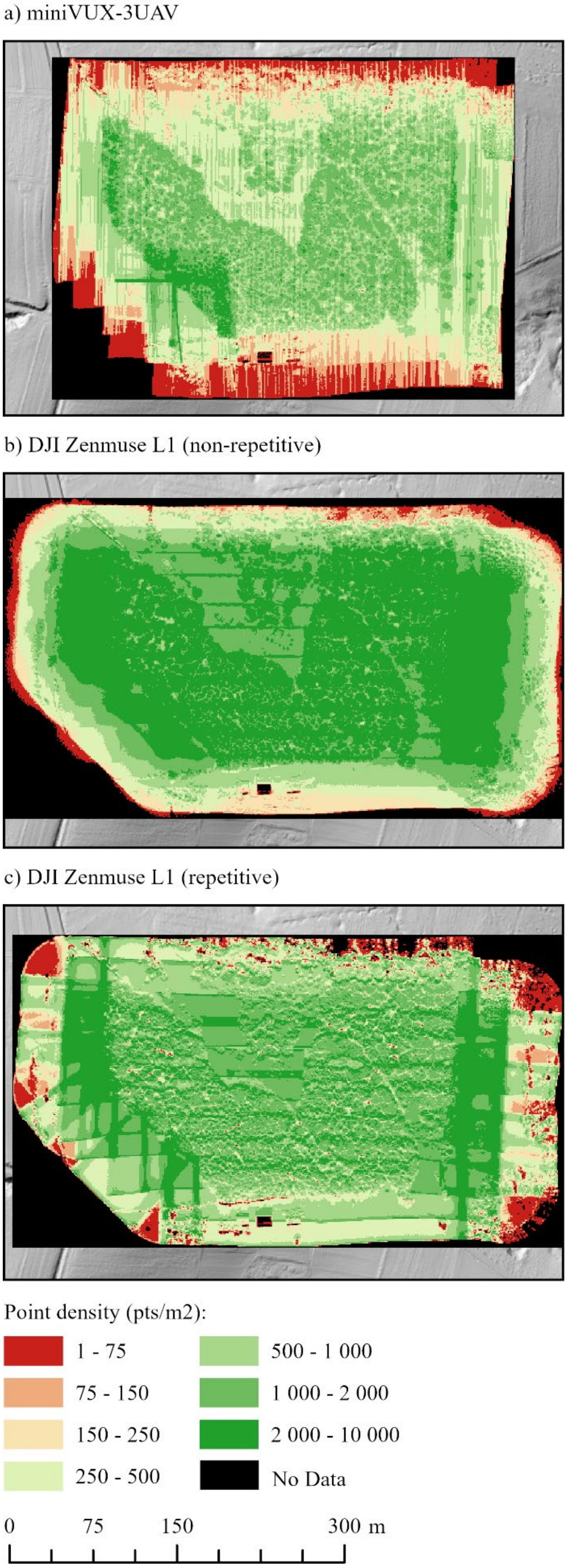


Figure 4. Point cloud density for the used UAV sensors, including points from all classes.

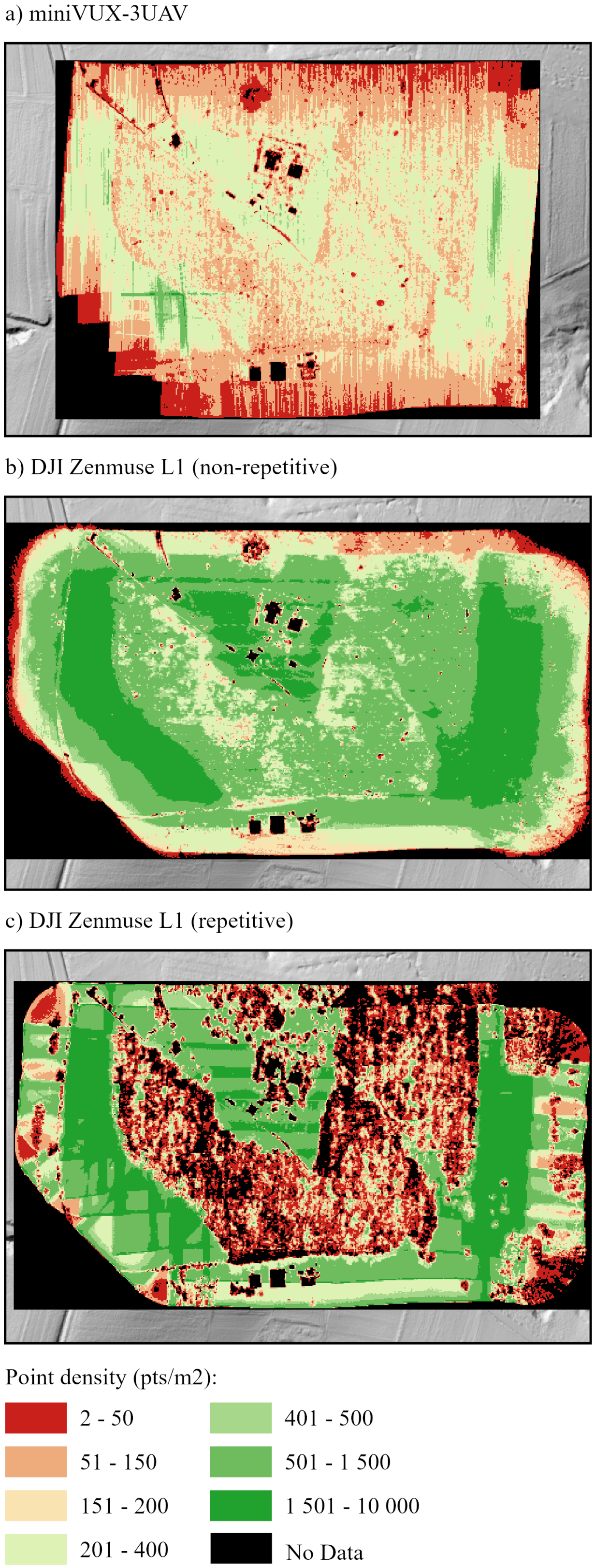
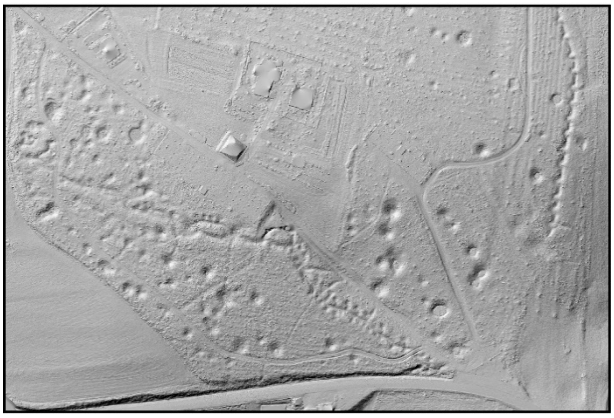


Figure 5. Point density on the ground from ULS data, after classification with in TerraScan (for Riegl miniVUX-3UAV dataset) and DJI Terra Pro software (for DJI Zenmuse L1 datasets).

a) miniVUX-3UAV

b) DJI Zenmuse L1 (non-repetitive)



c) DJI Zenmuse L1 (repetitive)

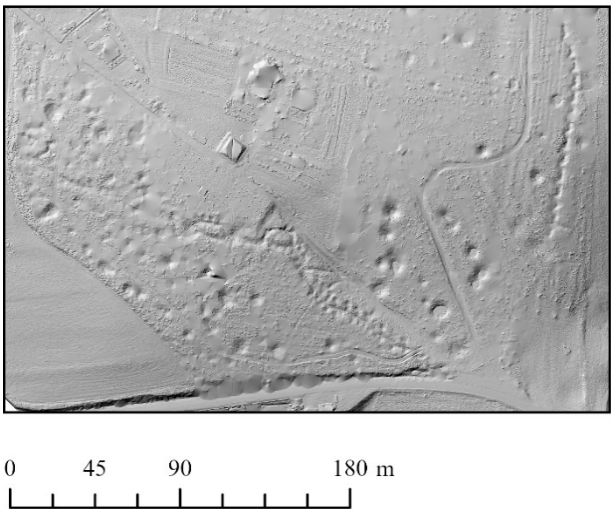
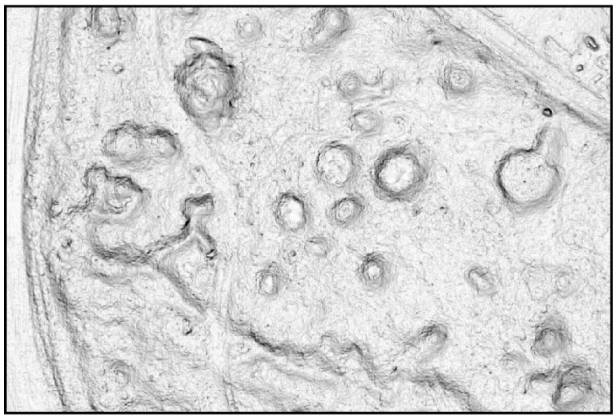


Figure 6. Shaded DTMs generated from ULS data from different sensors.

The point clouds from UAV laser scanners are characterized by higher point cloud density and different point cloud quality, thus their processing and classification can be more challenging and can differ depending on the software used. Some classification approaches can cause the classification to be more aggressive (more points in ground class, including e.g. lower parts of the tree trunks), other too preventive (less points classified as ground as expected). Thus, optimal parameter definition and correct point cloud classification are crucial for further interpretation of the DTMs.

In Figure 6, DTMs generated from UAV laser scanner point clouds are presented. Comparing to ALS DTMs (Fig. 2), the UAV DTMs seem to be more detailed and less smoothed. More details are visible on the hillshade model, which enables deeper interpretation of the archaeological site. Crucial elements are higher point cloud density and the leaf-off season of data acquisition. Comparing different DTMs from ULS between each other, in Fig. 6 the Riegl DTM seems to be very detailed, and in this scale it is similar to non-repetitive DTM from L1 laser scanner. The repetitive DTM is more smoothed and there are visible flat places, which result from filling no-data areas in the point cloud. The repetitive scanning pattern resulted in the lowest density of the points on the ground, what is also visible on the shaded DTM.

a) miniVUX-3UAV



b) DJI Zenmuse L1 (non-repetitive)

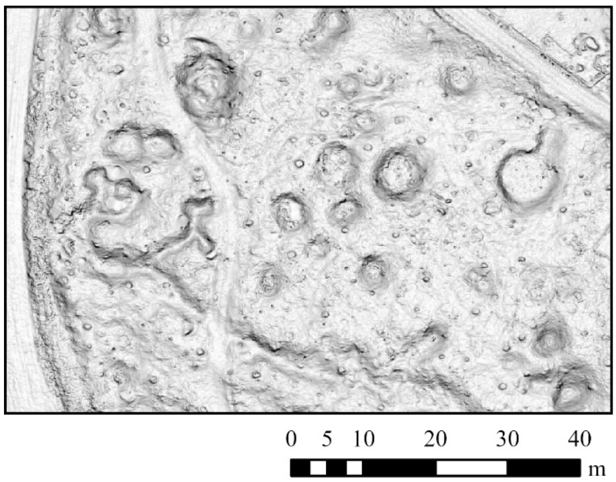


Figure 77. Part of the test side - the remains of the trenches, dugouts, and artillery shell craters (together with modern road) are visible. Visualisation of the blended slope map and shaded DTM for Riegl miniVUX-3UAV and DJI Zenmuse L1 (non-repetitive scan pattern).

Figures 7 and 8 present two more detailed (due to better scales) parts of the test side where the remains of the trenches, dugouts, and artillery shell craters are visible. Visualization of the blended slope map and shaded DTM for Riegl miniVUX-3UAV and DJI Zenmuse L1 (non-repetitive scan pattern). The figures do not show the results for repetitive scanning patterns as they were already indicated as giving the worst results based on previous analysis and visualization. Thus, the Riegl dataset and L1 non-repetitive point cloud were evaluated. The results showed that there are only slight differences between the DTMs. The L1 non-repetitive DTM is more smoothed in places with sudden height differences, and on the flat area, some dots are visible, which indicates small changes in height. This may be a result of the ground classification process conducted in DJI Terra. Despite these minor differences, all archaeological features are clearly visible on DTM from both UAV scanners.

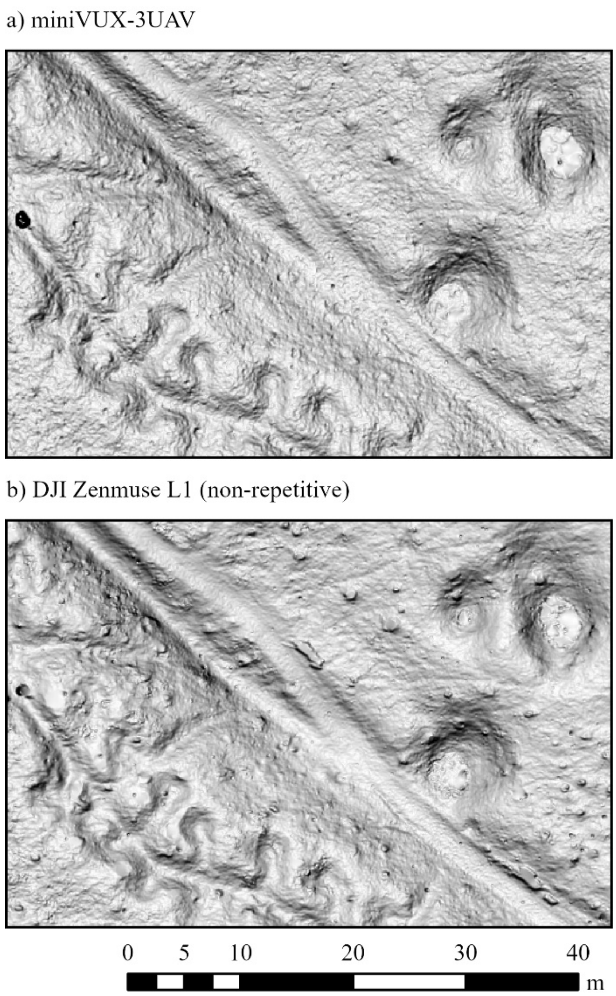


Figure 88. Part of the test side - the remains of the trenches, dugouts, and artillery shell craters are visible (together with modern road). Visualisation of the blended slope map and shaded DTM for Riegl miniVUX-3UAV and DJI Zenmuse L1 (non-repetitive scan pattern).

5. CONCLUSIONS

In this article, two laser scanners for UAVs were tested to analyze their possibilities for mapping archaeological sites. The tested laser scanners were: Riegl miniVUX-3UAV and DJI Zenmuse L1. The laser scanners differ from each other in their scanning systems, which results in different scanning patterns of the points on the ground.

In the presented results, the main difference that can be noticed is point density. L1 point clouds are characterized by higher point density; however, analyzing the density on the ground, the repetitive scanning pattern resulted in the lowest density (lower than for the Riegl laser scanner).
The acquired DTMs were analyzed taking into account different visualizations, which proved that products generated from ULS are significantly more detailed than ALS data. DTMs that have a higher spatial resolution have a better ability to represent terrain forms, which is particularly important in the context of archaeological research.

As the results show, the quality of the DTM is also strongly influenced by the type of scanning pattern – data acquired with DJI Zenmuse L1 with repetitive scanning patted do not have enough points on the ground for archaeological application. Finally, data collected by both scanners Riegl miniVUX-3UAV and DJI Zenmuse L1 with non-repetitive scan patterns are enough to identify remains of the World War I fortification and to identify craters created by different types of artillery. However, it should be mentioned that the classification of points on the ground can affect the quality of the DTM. The software used, and the classification parameters can result in both an over-assignment of points to ground class and an approach resulting in missing points in areas of real terrain. Optimization of the classification parameters is, therefore, crucial for further analysis and interpretation of the results.

Summarizing, ULS offers advantages over ALS data in archaeological investigations, especially due to the higher data density, but also the flexibility in data acquisition. The Riegl scanner showed significantly better product quality compared to data from the DJI L1 repetitive scan pattern, but the use of the L1 non-repetitive pattern allows for comparable results.

REFERENCES

Balsi, M., Esposito, S., Fallavollita, P., Melis, M. G., & Milanese, M. (2021). Preliminary archeological site survey by UAV-borne lidar: A case study. Remote Sensing, 13(3), 332.

Campana, S. (2017). Drones in archaeology. State-of-the-art and future perspectives. *Archaeological Prospection*, 24(4), 275-296.

Doneus, M., Briese, C., Fera, M., & Janner, M. (2008). Archaeological prospection of forested areas using full-waveform airborne laser scanning. *Journal of Archaeological Science*, *35*(4), 882-893.

Mandlburger, G., Kölle, M., Pöppl, F., & Cramer, M. (2023). Evaluation of Consumer-Grade and Survey-Grade UAV-LIDAR. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVIII-1/W3-2023,* 99–106.

Storch, M., Jarmer, T., Adam, M., & de Lange, N. (2021). Systematic approach for remote sensing of historical conflict landscapes with UAV-based laserscanning. *Sensors*, *22*(1), 217.

Roman, A., Ursu, T. M., Lăzărescu, V. A., Opreanu, C. H., & Fărcaș, S. (2017). Visualization techniques for an airborne laser scanning-derived digital terrain model in forested steep terrain: Detecting archaeological remains in the subsurface. Geoarchaeology, 32(5), 549-562.