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DITCH EDGE EXTRACTION AS A RESOURCE FOR ENVIRONMENTAL CONSERVATION AND MANAGEMENT

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Abstract

Land consolidation is one of the most important operations carried out on agricultural land to ensure effective land management, whether for agricultural production, land conservation or the preservation of historic land structures. It is a time- and cost-intensive process, typically spanning several years; therefore, any advancements that can reduce its duration are valuable. This study focuses on the identification of drainage and roadside ditch edges, which are measured at an initial stage of the consolidation process to update land use records. The aim of this study was to assess the accuracy with which ditch banks in agricultural areas can be delineated using publicly available, high-resolution LiDAR data from airborne laser scanning (ALS), with a point cloud density of 4 points per square meter. The study area was classified and a ditch class was extracted with a classification accuracy of Kappa index = 0.77. Then the edges were compared with ground-truth data obtained via GNSS RTK measurements. Survey points were recorded every 0.5 meters along the ditch edges and the distances to the nearest corresponding points were analyzed. The mean deviation across the entire study area was 0.92 meters, with a standard deviation of ±1.5 meters and a median of 0.42 meters. A significant impact of outlier data was observed. The obtained results indicate that this method is not sufficiently accurate for application in the land consolidation process, particularly in cases where ditch edges coincide with property boundaries. However, the accuracy achieved is adequate for updating land use records. To assess the upper limit of classification accuracy, two ditches were selected for in-depth analysis: a drainage ditch (mean deviation: 0.42 meters, median: 0.30 meters) and a roadside ditch (mean deviation: 0.46 meters, median: 0.38 meters). The improved accuracy observed in these cases highlights the potential for proposed method improvement.

***Keywords**: Land consolidation; Land conservation; Ditch edge detection; Flow Line Curvature; GIS; LiDAR;*

Introduction

Land consolidation is a crucial land management process that reorganizes insufficient land structures in the countryside, solves land conflicts and facilitates rural development. Land conservation is also a part of the process, as well as the protection of the traditional (historical) land structures or economy if adopted in a consolidation strategy. The process aims to reverse the excessive parcel fragmentation that has developed over time and enhance land structure by reducing non-usable plots [1]. In addition, properly conducted land consolidation has a positive or neutral impact on the environment. This ecological aspect is also considered in environmental

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studies or the assessment of the impact of the consolidation project on the environment. Therefore, the process is of high political importance in most of the transitional countries and is expected to be implemented in the shortest possible time [2, 3]. Nevertheless, the process is extremely labor-intensive and time-consuming due to the large project area and usually the many participants (landowners and users) with different expectations in the project. Therefore, many scientific publications present solutions to improve this process, both at the design and implementation stages. Several recent publications [4-8] show that scientists are working on ways to automate the land valuation process. It is important to note that the re-allotment is one of the most time-consuming and responsible phases of a land consolidation project. As the interests of the project participants change over time, there are a number of interests and negotiations between participants that require careful consideration. While preparing the land consolidation plan or re-allotment plan (at the re-allotment phase), it is recommended to divide the project area into sub-areas, the so-called complexes, with natural boundaries such as roads, water bodies and forest lines [9] and map the actual situation of land ownership. This process has a significant impact on the value of the merged land and thus on its eventual exchange between landowners. In our study, emphasis was placed on the detection and spatial recognition of ditches occurring in the land consolidation project area. Ditches, apart from field roads or designed plots, usually are one of the “invariable” objects, as the shapes are not changed during the entire land consolidation process. Their current shape is determined at the beginning of the process—during land consolidation project area determination (if the project area is aligned with ditches) or coordinating land parcels participating in the project. Further, the land consolidation project manager (land surveyor) aligns new land parcels next to such objects.

Ditches or to be specific, edges of each ditch, must be measured by a licensed land surveyor using a total station, Global Navigation Satellite Systems (GNSS) receiver or other surveying techniques. According to the Polish regulations, ditch bank points (vertexes) accuracy has to be at least 0.30m [10]. Such tolerance is due to the difficulty of recognizing an actual edge in the field, while modern equipment assures much higher accuracy. For example, the GNSS Real Time Kinematic (RTK) method with reference to the ASG-EUPOS (ASG—pol. Aktywna Sieć Geodezyjna, eng. Active Geodetic Network, EUPOS—European Position Determination System) GNSS permanent stations network usually does not exceed 0.03m horizontally [11, 12]. Precise identification of actual banks of the ditches can be particularly time-consuming in areas that are difficult to access (i.e., bushes, forests etc.), where the traditional equipment (e.g., total station) must be used. Therefore, the use of publicly accessible Light Detection and Ranging (LiDAR) data (published by the Polish Head Office of Geodesy and Cartography—HOGC) and its proper processing might speed up such work.

The use of high-resolution LiDAR data is increasingly appearing in the studies related to agricultural lands and ditch extraction [13] and ready-to-use ditch-pointing tools are emerging [14-16]. However, the literature review shows that identifying the ditch itself (not the edge) is the most common scope. Attempts to semi-automatically indicate ditch bunds [17] are presented with the use of different approaches—the DTM’s (Digital Terrain Model) shaded model or Topographic Position Index (TPI) [18]. Automatic ditch bottom indication is most commonly used in determining soil erosion risks [19, 20] or transfer of phosphorus [21]. Another use is the inventory of ditch networks for flood control in agricultural areas [22]. However, there are no articles offering ready-made solutions for ditch edge extraction. Also, methods of ditch recognition for land consolidation projects are rare [23].

It is noticeable that the use of various digital image filtering methods for feature extraction is a popular approach [24]. Ditches appear to be relatively easy to extract due to their structure. This is especially the case in typical agricultural areas, where crops (flat areas) are restricted where ditches start (abrupt slope) and the slope-to-elevation ratio is high. Hence the assumption is that in ditch extraction the main determinant will be the gradients along the line of the watercourse. The article evaluates the automation of such work, focusing on the accuracy with which ditch edges can be extracted automatically. Analyzing Digital Elevation Model (DEM) models (shaded model), the ditch can be identified, but there is a question—how accurately it can be extracted, since the available DEMs have a resolution of 1m. It was hypothesized that better results might be achieved by processing raw LiDAR data with a point cloud density of 4 pts/m². As a result of such an attempt, the new DEM was developed with a 0.25m resolution. Therefore, the aim (scientific hypothesis) of this paper is to determine whether LiDAR data can be used to detect the edges of ditches with sufficient accuracy to be used in land consolidation projects.

The article is divided into four chapters. The first is the introduction. The second (Materials and Methods) consists of the literature review and description of the test field, data and used analysis methods. The third (Results) describes the achieved results: for all data (56.5km) and two samples (240m and 280m) to demonstrate the best accuracy achieved. Finally, in the fourth (Conclusions and Discussion), the experiment is summarized and the results are discussed in the last chapter.

Materials and methods

Raster DTM grids generated from LiDAR point clouds have a wide range of use [25]. Practical applications, for example, include forest road mapping and cartography [26-28] where the level of the forest stand's accessibility significantly determines the forestry transport logistics and the concept of fire and flood protection as well as the general public land use is important within the land consolidation projects. DTM containing the height and slope allowed us to clearly identify 67% of roads with the help of created cross profiles. Another field where LiDAR DTMs found their application is the identification of medieval settlements or historical roads and historical relief forms and structures [29]. The DTM and orthophoto maps combination can be applied within the identification of the historical terraces to find their optimal land use management [30]. Microscale landforms and landslide areas can be analyzed using very high-resolution DTMs [31]. These could serve for detailed planning and localization of new land parcels within land consolidation projects [32]. The LiDAR DTMs were used to check the correctness of mountain peak heights against popular sources, e.g., topographic maps [33].

Study area

The study area covers the Niecieczа, Czyżów and Polesie Dębowe concessions, Tarnów district, Lesser Poland Voivodeship, southern Poland (Fig. 1). The area was subject to land consolidation and exchange processes between 2014 and 2022. It is a typically rural area, used for farming.

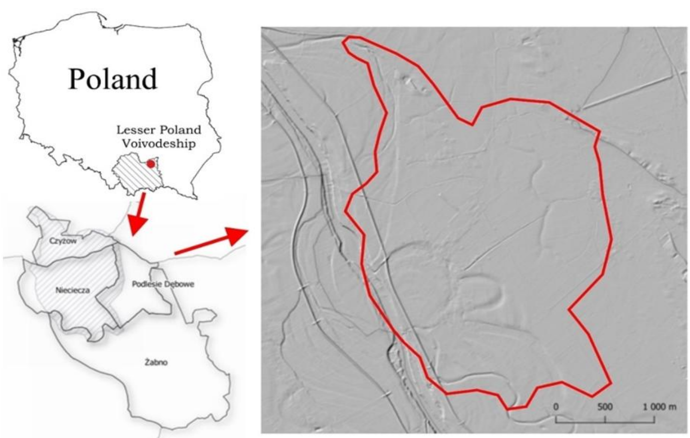

Fig. 1. Test area (part of the Żabno community, Lesser Poland Voivodeship, Poland) - limited by red contours - presented in 4pts/m² LiDAR digital terrain model, own study

Flat terrain, arable fields divided by a system of drainage ditches (
Fig. 2b). Along the roads - a network of roadside ditches (
Fig. 2a).

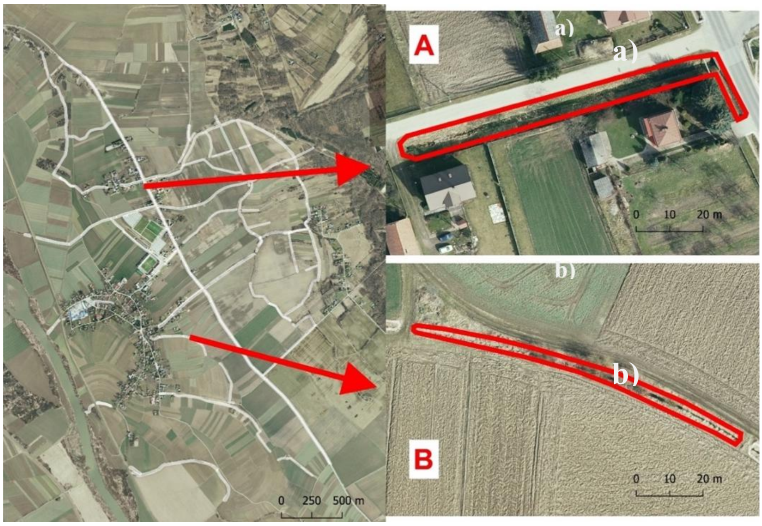

Fig. 2. Examples of analyzed ditch banks (red contours) shown on the aerial photo: A) roadside ditch no. 115, B) drainage/mid-field ditch no. 35, own study

The western boundaries are limited by the Dunajec River (
Fig. 2 - left) and its banks were not part of the experiment. The analyzed area has an area of approximately 714ha and consists of 84% arable land, buildings (8%), meadows and pastures (6%) and watercourses (2%).

Materials

Ditch edge survey data of approximately 56.5km of line was used for the study. Field measurements were made between November 2014 and April 2016. Various GNSS RTK receivers were used, referring to the ASG-EUPOS network. The network works in the PL-ETRF2000 reference frame, providing an average position accuracy of ±0.03m. However, due to the difficulty in identifying them, the ditches' edges were determined with higher uncertainty, but not exceeding ± 0.30m. Assuming that ditches in agricultural areas and in the study area are roughly 2-3m wide, the available DEM models with a resolution of 1m are not accurate enough. Therefore, it was decided to use the HOGC's LiDAR data [34] with a point cloud density of 4pts/m² (mean elevation error ±0.15m) and create a DEM model with a higher resolution of 0.25m based on this data. The HOGC provides two data sets from 2011 and 2019 for the area of the whole state. After comparing these data with the measured ones, the 2019 data were used for further studies. A total of 11 LiDAR sample data sets were used.

Methods

A DEM with a grid of 0.25m was generated from publicly available LiDAR data. The ground surface was interpolated using the Nearest Neighbor method. The DEM model was then processed to make the edges of the ditches as visible as possible. After an extensive analysis of available algorithms for processing spatial data and images, an algorithm implemented in SagaGIS 7.8.2 [35] software called Flow Line Curvature (FLC) was selected. This algorithm determines the curvature of flow lines that are perpendicular to the contours [36]. Within this algorithm, several methods are available for generating DEM derivatives. After analyzing the results obtained in the test field, the 2nd order polynomial was chosen [37], which is a commonly used function to interpolate or approximate local area [38, 39].

For the extraction of the ditches, the Flow Line Curvature input image was processed in the MATLAB 2019a [40] environment according to the following steps:

1) filtering with a median filter—noise removal;
2) Sobel filter and thresholding—edge extraction and binary image storage;
3) morphological filters—dilation, erosion, dilation, gap filling and erosion;
4) removal of small pixel groups;
5) saving to a binary file.

In the next step, the raster image using ArcGIS Desktop Advanced v.10.6.1 with Spatial Analyst extension [41] was converted into a vector according to the following steps:

6) conversion of raster to polygon (with the option to simplify the polygon);
7) conversion of a polygon to lines (with and without line simplification).

Also in the ArcGIS environment, a number of operations were performed to evaluate obtained results. First, the error matrix was determined and the Kappa index was calculated *J. Cohen* [42]. Then, taking into account similar studies provided by *N. Borowiec and U. Marmol* [24], DTM resolution and the shape and size of the ditches, it was decided to base the accuracy analysis on measuring the distance between the measured line and the generated line at an interval of 0.5m [24]. Points were generated every 0.5m on the automatically determined lines and the measured lines. The distances from each point on the measured line to the nearest point on the extracted line were determined. Basic statistics were calculated for the distances obtained and the results are presented in graphs.

Results

A derived DEM was then generated using the Flow Line Curvature algorithm, making the ditches more distinct (Fig. 3). In the next step, drainage ditches and roadside ditches were detected from the Flow Line Curvature image, where grey lines are measured and black lines are generated (

Fig. 4). The analyses were performed for two sets: the whole data (56.5km) and two ditches chosen from it. The selected examples are roadside ditch no. 115 (Fig. 3a) and the other drainage/mid-field ditch no. 35 (Fig. 3b). Both examples are extracted in their entirety, i.e., there is no disturbance, e.g., edge erosion. They are therefore a sample of favorable site conditions. The results obtained for them are a guide to the upper limit of the method used. Additionally, they illustrate the study and the issues related to extraction.

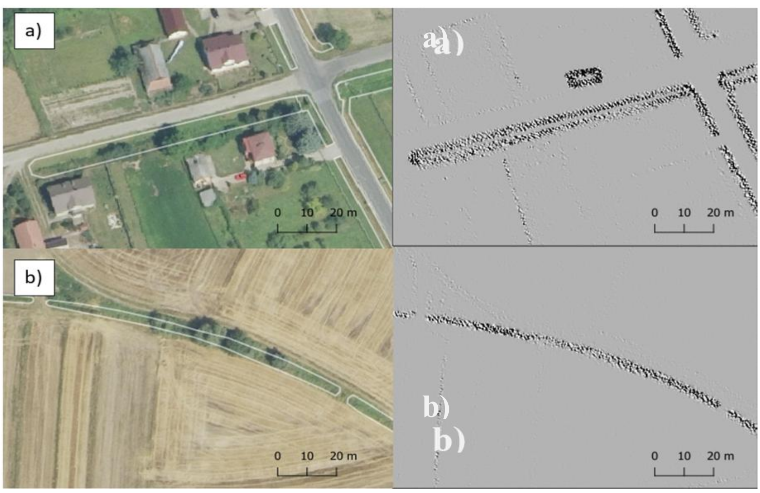

Fig. 3. Example part of the study area. Top image (a) roadside ditch no. 115, bottom image (b) drainage/mid-field ditch no. 35. Measured ditch edges (white line) against the orthophotos (left) and the DEM derivative generated with the Flow Line Curvature algorithm (right), own study

Fig. 4. Shape of ditches in the study area, own study

The best extracted were roadside ditches. They run on both sides of the main road (central part of the area). Some of them (on the eastern side) were not graded at all. These are places where the ditches were very shallow. Due to the time discrepancy between the field measurements and the LiDAR scanning, we are not able to provide a precise reason for such a situation. There may be various reasons, i.e., it was an erosion. Also, in the southern part of the site, some of the ditches were not extracted. Here the ditches had a more complex shape in cross-section and the edges of the ditches were less well recognized. In general, the number of sites where ditches have not been identified is higher than the number of sites where ditches have been misclassified. The extracted edges of the ditches are shown in more detail in the example (Fig. 5, 6 and 7). On figures 6 and 7, edges measured in the field are marked by grey contours, generated automatically without line simplification by a thin polygonal chain and generated automatically with line simplification by a thick black line.

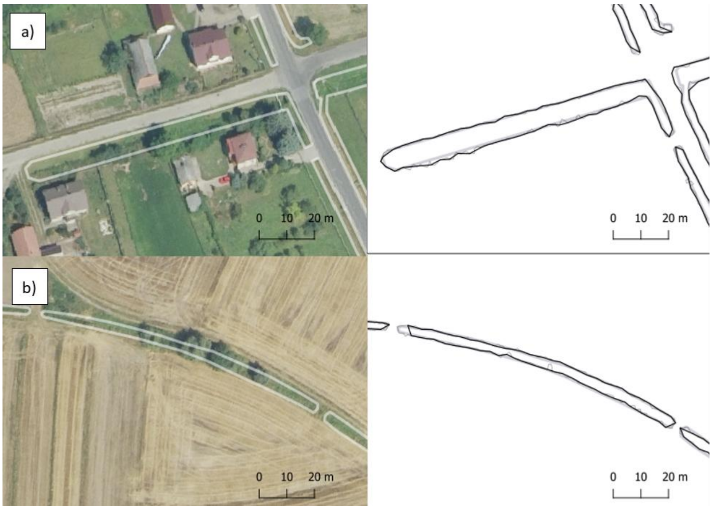

Fig. 5. Examples: (a) roadside ditch no. 115, (b) drainage/mid-field ditch no. 35. On the left edges observed in the field (white) on the orthophoto map, on the right measured and extracted (black contours), own study

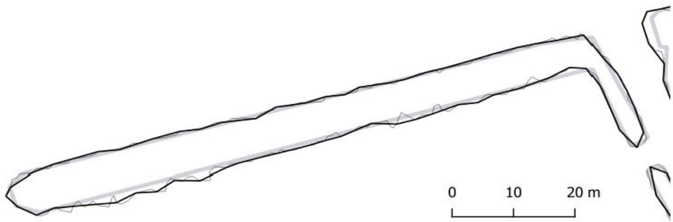

Fig. 6. Example ditch no. 115, own study

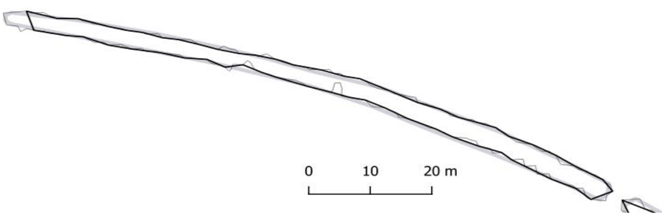

Fig. 7. Example ditch no. 35, own study

Figures 5 and 7 illustrate the impact of the generalization process on the shape of edges, using ditch No. 35 as an example. The western end of the ditch exhibits excessive generalization, whereas two outliers in the central part were reduced (but not entirely). This process was executed automatically in ArcGIS Desktop Advanced version 10.6.1 with the Spatial Analyst extension. Specifically, the "Convert Raster to Polygon" (CRtP) tool was used. This tool simplifies the resulting polygon by reducing the number of segments while preserving the object's overall shape. The CRtP tool in ArcGIS probably relies on the Douglas-Peucker generalization algorithm [43]. The software documentation and developers do not explicitly confirm this. However, its role as a benchmark in cartographic generalization and implementation in the ArcGIS toolbox leads us to think so.

The efficiency of the automatic classification was, according to the Kappa index, 77% (Table 1), i.e., substantial [44-46]. This accuracy rate ranges from 0 to 1, where 1 represents 100 percent accuracy. The user's accuracy (U_Accu.) shows false positives, where pixels are incorrectly classified as a known class when they should have been classified as something else (Table 1). The Total row shows the number of points that should have been identified as a given class, according to the reference data. The producer's accuracy (P_Accu.) is a false negative, where pixels of a known class are classified as something other than that class. The Total column shows the number of points that were identified as a given class, according to the classified map. The classification evaluation was performed in the ArcGIS Desktop Advanced v.10.6.1 software.

Table 1. Presentation of the individual components of the Kappa index, where: C_0 is a no ditch class; C_1 is a ditch class; Total is the number of points that should have been identified as a given class; U_Accu. is a user's accuracy and P_Accu. is a producer's accuracy

ClassValue		Ground Truth C_0	C_1	Total	U_Accu.	Kappa
Classified	C_0	24891	108	24999	0.9957	0
	C_1	5544	19456	25000	0.7782	0
Total		30435	19564	49999	0	0
P_Accu.		0.8178	0.9945	0	0.8870	0
Kappa		0	0	0	0	0.774

The automatically generated ditch edges (with the simplified shape) were compared with GNSS measurements. Both sets consisted of points at intervals of 0.5m on all lines. The comparison was based on calculating the distance between the nearest points from both sets, i.e., the generated point was compared with the nearest one from the field survey, with the assumed maximum tolerance of 10m. In total, 100 251 distances from a pair of points were calculated (Fig. 8). The average distance was 0.92±1.50m (Table 2), but the median was significantly lower (0.42m).

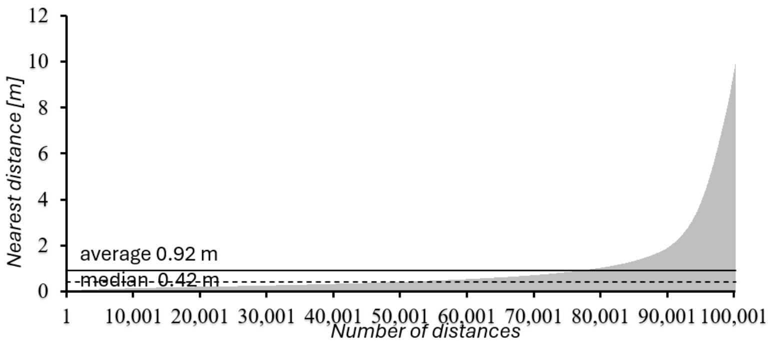

Fig. 8. Graph of the distribution of the distance between points on the measured and extracted lines, with the mean value (black solid line) and median of distances (black dashed line) for all ditch edges, own study

Table 2. Basic statistics for ditch edge recognition (GNSS RTK vs. generated from LiDAR) for all ditches (100 251 distances) and samples (no. 35–439, no. 115–489 distances)

Coefficient [m]	All ditches	No. 35	No. 115
Mean	0.92	0.42	0.47
Standard dev.	1.50	0.53	0.33
Median	0.42	0.40	0.34
Max	10.00*	3.70	1.69
Min	0.00	0.02	0.01

* maximum assumed tolerance.

While most distances fall below the mean, its distribution is distorted by outliers (Fig. 9). The distribution resembles a chi-square distribution and a concordance test ($\alpha = 0.05$) rejects that hypothesis. The results indicate a higher proportion of values below the mean (+8.1 percentage points) against what the chi-square distribution suggests, whereas less between mean, double mean and next intervals (up to 5.50m). A slight increase is observed only in intervals exceeding 5.5m, up to 10m (+1 pp). Given that the average ditch width is typically 2-3m, this distribution suggests that the algorithm's radius parameter (10m) was too large. Consequently, the results may have been contaminated by incorrectly identified points, such as those originating from a ditch on the opposite side of the road.

For selected samples, the achieved results are better (Table 2). No. 35 is characterized by a mean distance of 0.42 ± 0.53m (Fig. 10). The histogram (Fig. 11) shows that most distances (95.7%) are below 0.90m.

In Fig. 7 it is noticeable that simplification of the western ditch end influences results. Without this part (5% of the sample), the average value would be 0.32 ± 0.17m (median 0.29m). Therefore, the results may show the accuracy upper limit of the performed experiment, assuming that no gross error was made by the simplification method. Ditch No. 115 is characterized by: 0.47 ± 0.33m. The simplification has its influence on the eastern ditch end (Fig. 6), but it's less than 1% of points and does not have any significant impact on results (Fig. 12). The major difference between LiDAR and GNSS is on the south-western part (the influence of housing parcel and the fence, possible terrain levelling). Elimination of that part decreases the data by 10% and corrects the results to 0.38 ± 0.21m (median 0.34m). The archived values for ditch No. 35, No. 115 and its adjusted ("cleaned") versions, were tested: Welch's t-test for means [47] and Levene's test for variances [48]. There is no evidence to reject the null hypothesis of median and variance equality for No. 35 and No. 115. After data "cleaning," the null hypothesis should be rejected and be considered that means and variances (for e.g. No. 35 and "cleaned" No. 35) are better (lower). The last test (both sets "cleaned") tells that the means differences, as the variances. Surprisingly, after cleaning the data, the two samples are statistically different. This is despite to the fact that for No. 115 10% of the points from the most mismatched area were removed. Ditch No. 35 is a mid-field one, so its surroundings lack of any obstacles (bushes, tress etc.). Ditch No. 115 is not located so favorably (Fig. 13). Major outliers are noticed in the investment area (housing), where numerous plantings are located (Fig. 5).

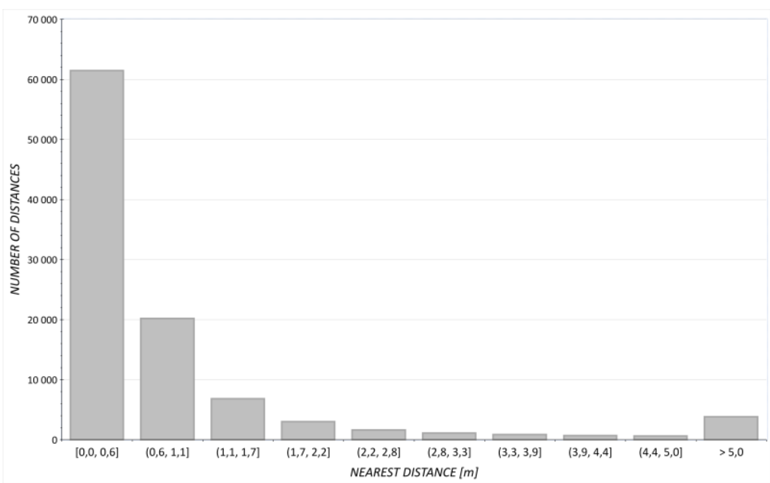

Fig. 9. Histogram showing the distribution of nearest distances between points on the lines measured and generated for all ditch edges, own study

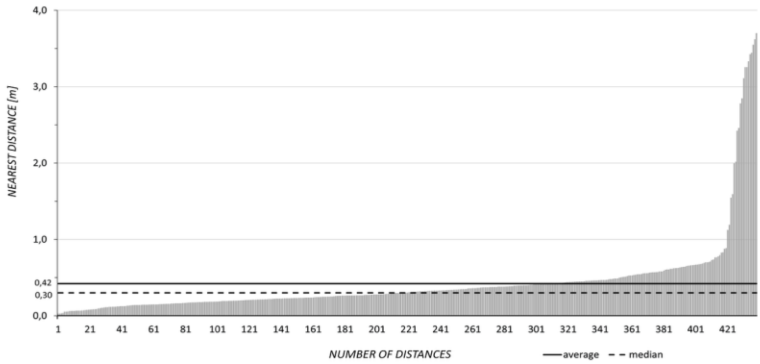

Fig. 10. Ditch edge No. 35. Plot of the distribution of distance values between points on the measured and extracted lines, together with the mean value - black solid line and median - black dashed line, own study

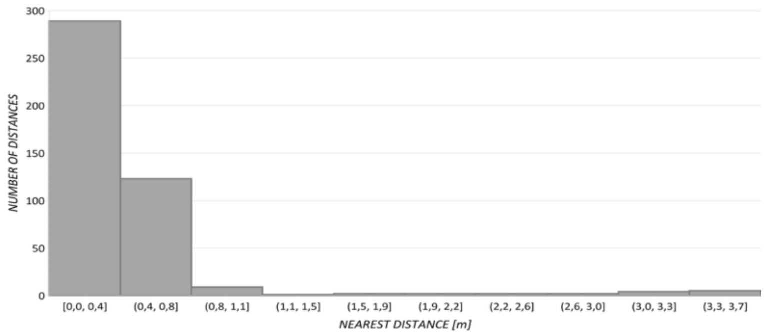

Fig. 11. Histogram of the distribution of distance values between points on the measured and extracted line for the edge of ditch No. 35, own study

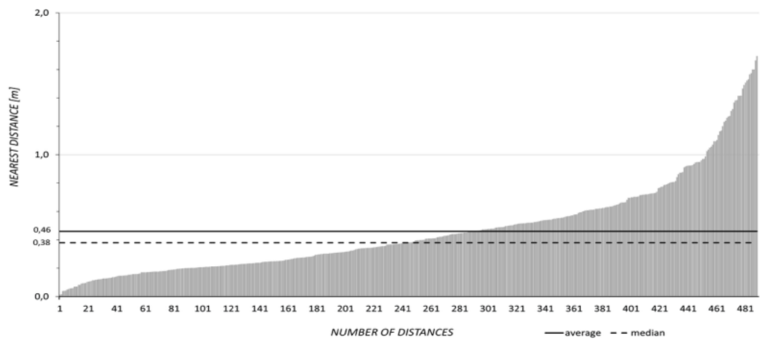

Fig. 12. Ditch edge No. 115. Plot of the distribution of distance values between points on the measured and extracted lines, together with the mean value - black solid line and median - black dashed line, own study

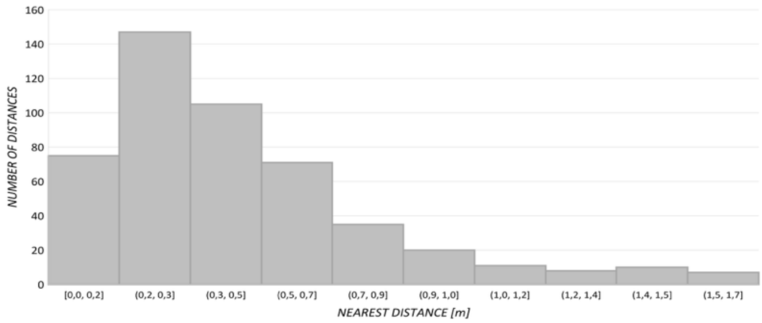

Fig. 13. Histogram of the distribution of distance values between points on the measured and extracted line for the edge of ditch No. 115, own study

Discussions

This article presents the use of open-access LiDAR data (in Poland available at 4 pts/m²) to detect the ditch edges. The preliminary experiment was performed for 56.5km of ditches located in the southern part of Poland. LiDAR data (from 2019) were compared with GNSS RTK observations (from 2014-2016). Field measurements were referred to the geodetic control network (ASG-EUPOS) in the PL-ETRF2000 terrestrial frame and conducted with an average accuracy of ± 0.03m. However, the edge of the ditch is not clearly identifiable in the field, so the real uncertainty of the edges can be lower. Officially, the Polish regulation of land surveying standards does not allow exceeding an accuracy of 0.30m. Edge extraction was performed on a 7-step procedure based on the Flow Line Curvature algorithm in SagaGIS 7.8.2 software. The results obtained for 100,251 pairs of points (LiDAR and GNSS) show a mean difference of 0.92 ± 1.50m (median 0.42m). To check the upper uncertainty limit of the method, two ditches (No. 35 and – 439 pair of points and No. 115 - 489) were selected for in-depth analysis. Their results are significantly better: (No. 35) 0.42 ± 0.53m (median 0.30m) and (No. 115) 0.47 ± 0.33m (median 0.34m). When the gross errors were eliminated, the results show (No. 35) 0.32 ± 0.17m (median: 0.29m) and (No. 115) 0.38 ± 0.21m (median 0.34m). However, the cleaning decreased the sample by 5% and 10%, respectively.

The analyses carried out for the experiment allow us to draw the following conclusions:

1) the Flow Line Curvature algorithm on the studied agricultural terrain shows the course of the ditches and their edges very clearly;
2) despite the overall good classification fit (Kappa index 0.77), the main reason for the poor accuracy of the ditch edge extraction is the locations where the ditches were not detected; the assumed searching radius (10 m) to compare LiDAR and GNSS points was too large and may have affected the results by erroneously identified values;
3) the major differences appeared where the edge of the ditch did not have a distinctive slope from its surrounding field;
4) outliers appearing (standard deviation ± 1.50m) were mainly due to ditches not being identified in the area. These are locations where the ditches were very shallow (eastern part of the site). It may be related to the time shift in the measurements. In the southern part of the site, missing ditches were also observed; here they had less distinct edges and their shape in cross-section was more complex;
5) used algorithm for simplification of extracted (LiDAR) edges (Douglas-Peucker, 1973) may influence data by adding gross errors; an appropriate algorithm for simplification without changing the ditch ends should be considered.

The results do not allow us to conclude that the tested method is appropriate in land consolidation, particularly in places where ditch edges are property boundaries. Nevertheless, the results were satisfactory on most sites, indicating that such a methodology could be optimized and developed into a useful tool for such a process. The large-area field GNSS measurements are time-consuming and expensive (personal costs); thus, the remote sensing methods may provide an effective workflow for updating the land status. Currently, the studies might be used for updating the land use status or preliminary analysis in land consolidation works, e.g., showing which area needs more attention in field measurements.

The proposed method can also find its application in fields such as environmental protection or archaeology, where the edge of the ditch does not have to be indicated with high precision. The edges of drainage ditches or natural gullies can help in assessing the flow of surface water, identifying areas at risk of erosion and managing stormwater. Identification of main water corridors can support decisions on the construction of water retention systems or plans to counteract water-related disasters. Analysis of the variability of the ditch edges can help in assessing the impact of climate change on floodplains or on the spread of invasive species that can use ditches as a new environment.

In archaeological research in areas that have not yet been discovered, the excavated ditch edges can help in the search for unknown burial structures, ancient cities or forts. They can indicate existing ancient irrigation systems or drainage channels.

The tested method was developed on relatively low-density LiDAR data (4 pts m^2), with a few-year lag between GNSS and LiDAR data. Therefore, the data limitations might have an influence, decreasing the method's accuracy. A higher point cloud density (and a better temporal match with the GNSS) would probably have allowed the edges of the ditches to extrude them more precisely. The collection of 10-15 pts/m^2 issue is no longer relevant due to the popularity of UAVs and their relatively low cost and time flexibility. Therefore, the experiment must be treated as a preliminary analysis, which shows the path for further studies on relevant GIS methods and LiDAR point density. The perspective of method development may be summarized in a few directions:

1) since the number of two in-depth studies is not statistically significant, the number of sample ditches needs to be increased and LiDAR and GNSS RTK data need to be collected in the same epoch as much as possible;
2) the selected LiDAR 4 pts/m^2 should be compared with a denser one, e.g., 12 pts/m2;
3) an assumed searching radius (10 m) should be shortened and correspond to the mean ditch width in the study area or – a better way – should be calculated for each ditch separately, based on its individual width;
4) the simplification method of extruded edges should be more appropriate - the optimal should be searched in modern cartographic generalization algorithms, e.g., [49-51], with particular emphasis on those preserving the beginnings/ends of the ditch.

Conclusions

The proposed method, applied to open-access LiDAR data (4 points/m^2), enabled the extraction of ditch edges with a mean positional difference of 0.92 ± 1.50 m overall. After outlier removal in selected cases, the accuracy improved to $0.32–0.38 \pm 0.17–0.21$ m. At its current stage of development, the method does not meet the accuracy requirements for land consolidation projects (≤ 0.30 m). Nevertheless, it demonstrates potential despite limitations caused by temporal data mismatch and local terrain characteristics. Owing to its cost-effectiveness, the method appears promising for preliminary land use updates, environmental monitoring, and archaeological investigations. Future improvements should focus on the optimization of cartographic generalization algorithms and the application of higher-density LiDAR data (> 10 points/m²).

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References

[1] B. Krzanowski, S. Kułaga, I. Basista, Ł. Borowski, K. Maciuk, *GIS Tools in the Conservation and Sustainable Development National Parks, Forests And Rural Areas*, **International Journal of Conservation Science**, **15**, 2024, pp. 547-560. https://doi.org/10.36868/IJCS.2024.01.11.

[2] G. Pašakarnis, V. Maliene, R. Dixon-Gough, N. Malys, *Decision support framework to rank and prioritise the potential land areas for comprehensive land consolidation*, **Land Use Policy**, **100**, 2021, Article Number: 104908. https://doi.org/10.1016/J.LANDUSEPOL.2020.104908.

[3] R. Dixon-Gough, *The Role of the State and Individual in Sustainable Land Management*, **The Role of the State and Individual in Sustainable Land Management**, 2006, pp. 159-176.

[4] J. Janus, E. Ertunç, *Towards a full automation of land consolidation projects: Fast land partitioning algorithm using the land value map*, **Land Use Policy**, **120**, 2022, Article Number: 106282. https://doi.org/10.1016/J.LANDUSEPOL.2022.106282.

[5] M. Siejka, M. Ślusarski, M. Mika, P. Leń, *Modernizacja ewidencji gruntów i budynków w świetle obowiązujących przepisów prawnych*, **Infrastruktura i Ekologia Terenów Wiejskich**, **II**(1), 2016. https://doi.org/10.14597/INFRAECO.2016.2.1.026.

[6] P. Leń, M. Maciąg, K. Maciąg, *Design of an Automated Algorithm for Delimiting Land Use/Soil Valuation Classes as a Tool Supporting Data Processing in the Land Consolidation Procedure*, **Sustainability**, **15**, 2023, Article Number: 8486. https://doi.org/10.3390/SU15118486.

[7] P. Leń, K. Maciąg, M. Maciąg, J. Wójcik-Leń, K. Kocur-Bera, *Automated Processing of Data in the Comparative Estimation of Land Value during Land Consolidation Works*, **Sustainability, 15,** 2023, Article Number: 8110. https://doi.org/10.3390/SU15108110.

[8] A. Tezcan, K. Büyüktaş, Ş.T. Akkaya Aslan, *A multi-criteria model for land valuation in the land consolidation*, **Land Use Policy**, **95**, 2020, Article Number: 104572. https://doi.org/10.1016/J.LANDUSEPOL.2020.104572.

[9] T. Veršinskas, M. Vidar, M. Hartvigsen, K. Mitic Arsova, F. van Holst, M. Gorgan, *Legal guide on land consolidation*, **FAO**, 2020. https://doi.org/10.4060/ca9520en.

[10] * * *, MRPiT, *Rozporządzenie w sprawie standardów technicznych wykonywania geodezyjnych pomiarów sytuacyjnych i wysokościowych oraz opracowania i przekazywania wyników tych pomiarów do państwowego zasobu geodezyjnego i kartog*, **Dziennik Ustaw**, 2021, pp. 11.

[11] R. Szpunar, J. Walo, A. Pachuta, G. Astronomy, *Utilization of the ASG-EUPOS system*

NAWGEO service in monitoring displacement, **Reports on Geodesy**, **87**, 2009, pp. 337-342.

[12] W. Magiera, I. Vārna, I. Mitrofanovs, G. Silabrieds, A. Krawczyk, B. Skorupa, M. Apollo, K. Maciuk, *Accuracy of Code GNSS Receivers under Various Conditions*, **Remote Sensing**, **14**, 2022, Article Number: 2615. https://doi.org/10.3390/rs14112615.

[13] J. Roelens, B. Höfle, S. Dondeyne, J. Van Orshoven, J. Diels, *Drainage ditch extraction from airborne LiDAR point clouds*, **ISPRS Journal of Photogrammetry and Remote Sensing**, **146**, 2018, pp. 409-420. https://doi.org/10.1016/j.isprsjprs.2018.10.014.

[14] J. Roelens, I. Rosier, S. Dondeyne, J. Van Orshoven, J. Diels, *Extracting drainage networks and their connectivity using LiDAR data*, **Hydrological Processes**, **32**, 2018, pp. 1026-1037. https://doi.org/10.1002/hyp.11472.

[15] H. Sangireddy, C.P. Stark, A. Kladzyk, P. Passalacqua, *GeoNet: An open source software for the automatic and objective extraction of channel heads, channel network, and channel morphology from high resolution topography data*, **Environmental Modelling & Software**, **83**, 2016, pp. 58-73. https://doi.org/10.1016/j.envsoft.2016.04.026.

[16] P. Passalacqua, P. Belmont, E. Foufoula-Georgiou, *Automatic geomorphic feature extraction from lidar in flat and engineered landscapes*, **Water Resources Research**, **48**, 2012. https://doi.org/10.1029/2011WR010958.

[17] J. Graves, R. Mohapatra, N. Flatgard, *Drainage Ditch Berm Delineation Using Lidar Data: A Case Study of Waseca County, Minnesota*, **Sustainability**, **12**, 2020, Article Number: 9600. https://doi.org/10.3390/su12229600.

[18] L. Stanislawski, T. Brockmeyer, E. Shavers, *Automated road breaching to enhance extraction of natural drainage networks from elevation models through deep learning*, **International Society for Photogrammetry and Remote Sensing**, 2018, pp. 671-678. https://doi.org/10.5194/isprs-archives-XLII-4-597-2018.

[19] X. Han, P. Lv, S. Zhao, Y. Sun, S. Yan, M. Wang, X. Han, X. Wang, *The Effect of the Gully Land Consolidation Project on Soil Erosion and Crop Production on a Typical Watershed in the Loess Plateau*, **Land**, **7**, 2018, Article Number: 113. https://doi.org/10.3390/land7040113.

[20] E. Monsieurs, J. Poesen, M. Dessie, E. Adgo, N.E.C. Verhoest, J. Deckers, J. Nyssen, *Effects of drainage ditches and stone bunds on topographical thresholds for gully head development in North Ethiopia*, **Geomorphology**, **234**, 2015, pp. 193-203. https://doi.org/10.1016/j.geomorph.2015.01.011.

[21] M. Shore, P. Jordan, P.-E. Mellander, M. Kelly-Quinn, A.R. Melland, *An agricultural drainage channel classification system for phosphorus management*, **Agriculture, Ecosystems & Environment**, **199**, 2015, pp. 207-15. https://doi.org/10.1016/j.agee.2014.09.003.

[22] F. Cazorzi, G.D. Fontana, A. De Luca, G. Sofia, P. Tarolli, *Drainage network detection and assessment of network storage capacity in agrarian landscape*, **Hydrological Processes**, **27**, 2013, pp. 541-553. https://doi.org/10.1002/hyp.9224.

[23] H. Eroğlu, Y. Sisman, *Arazi Toplulaştırması Dağıtım İşleminde Tek Amaçlı Genetik Algoritmanın Kullanılması*, **Geomatik**, **5**, 2020, pp. 91-99. https://doi.org/10.29128/geomatik.566666.

[24] N. Borowiec, U. Marmol, *Using LiDAR System as a Data Source for Agricultural Land Boundaries*, **Remote Sensing**, **14**, 2022, Article Number: 1048. https://doi.org/10.3390/rs14041048.

[25] M. Jaboyedoff, T. Oppikofer, A. Abellán,. M. Derron, A. Loye, R. Metzger, A. Pedrazzini, *Use of LIDAR in landslide investigations: a review*, **Natural Hazards, 61**, 2012, pp. 5–28

https://doi.org/10.1007/s11069-010-9634-2M.
[26] I. Sačkov, R. Smreček, J. Tuček, *Forest transportation survey based on airborne laser scanning data and GIS analyses*, **GIScience and Remote Sensing**, **51**, 2014, pp. 83-98. https://doi.org/10.1080/15481603.2014.883213.
[27] I. Sačkov, M. Kardoš, P*oint clouds from airborne laser scanning and aerial images for forestry*, **33. Wissenschaftlich-Technische Jahrestagung Der DGPF, Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V**., Freiburg, 2013, pp. 160-168.
[28] M. Kardoš, I. Sačkov, J. Tomaštík, I. Basista, Ł. Borowski, M. Ferenčík, *Elevation Accuracy of Forest Road Maps Derived from Aerial Imaging, Airborne Laser Scanning and Mobile Laser Scanning Data*, **Forests**, **15**, 2024, Article Number: 840. https://doi.org/10.3390/f15050840.
[29] M. Slámová, B. Belacek, J. Beljak, N. Pažinová, F. Chudý, *Dependence of the Medieval Settlements and Historical Roads to the Natural Environment Around the Deserted Castle in Zvolen (Slovakia)*, **Procedia - Social and Behavioral Sciences**, **120**, 2014, pp. 213-223. https://doi.org/10.1016/j.sbspro.2014.02.098.
[30] M. Slámová, F. Chudý, J. Tomaštík, M. Kardoš, J. Modranský, *Historical Terraces – Current Situation and Future Perspectives for Optimal Land Use Management: The Case Study of Čierny Balog*, **Annales-Anali Za Istrske in Mediteranske Studije - Series Historia et Sociologia**, **29**, 2019, pp. 85-100. https://doi.org/10.19233/ASHS.2019.07.
[31] F. Chudý, M. Slámová, J. Tomaštík, R. Prokešová, M. Mokroš, *Identification of micro-scale landforms of landslides using precise digital elevation models*, **Geosciences**, **9**, 2019, Article Number: 117. https://doi.org/10.3390/geosciences9030117.
[32] M. Balawejder, A. Warchoł, K. Konttinen, *Energy Efficiency in Agricultural Production—Experience from Land Consolidation in Poland and Finland*, **Energies**, **16**(22), 2023, Article Number: 7598. https://doi.org/10.3390/EN16227598.
[33] M. Apollo, J. Mostowska, K. Maciuk, Y. Wengel, T.E. Jones, J.M. Cheer, *Peak-bagging and cartographic misrepresentations: a call to correction*, **Current Issues in Tourism**, **24**(14), 2021, pp. 1970-1975. https://doi.org/10.1080/13683500.2020.1812541.
[34] * * *, **Head Office of Geodesy and Cartography**, *Geoportal.gov.pl*, 2009.
[35] O. Conrad, B. Bechtel, M. Bock, H. Dietrich, E. Fischer, L. Gerlitz, J. Wehberg, V. Wichmann, J. Böhner, *System for Automated Geoscientific Analyses (SAGA) v. 2.1.4*, **Geoscientific Model Development**, **8**(7), 2015, pp. 1991-2007. https://doi.org/10.5194/gmd-8-1991-2015.
[36] V. Olaya, *Chapter 6 Basic Land-Surface Parameters*, **Developments in Soil Science**, **33**, 2009, pp. 141-169. https://doi.org/10.1016/S0166-2481(08)00006-8.
[37] L.W. Zevenbergen, C.R. Thorne, *Quantitative analysis of land surface topography*, **Earth Surface Processes and Landforms**, **12**(1), 1987, pp. 47-56. https://doi.org/10.1002/esp.3290120107.
[38] Ł. Borowski, M. Banas, A*pplication of Robust Estimation in Polynomial Modelling*, **2018 Balt. Geod. Congr. (BGC Geomatics)**, **IEEE**, 2018, pp. 62-66. https://doi.org/10.1109/BGC-Geomatics.2018.00018.
[39] M. Ligas, P. Banasik, *Local height transformation through polynomial regression*, **Geodesy and Cartography**, **61**(1), 2012, pp. 3-17. https://doi.org/10.2478/v10277-012-0018-5.
[40] * * *, The MathWorks Inc., *MATLAB R2019a*, 2019.
[41] * * *, ESRI, *ArcGIS Desktop 10.6.1*, 2018.
[42] J. Cohen, *A Coefficient of Agreement for Nominal Scales*, **Educational and Psychological**

Measurement, **20**(1), 1960, pp. 37-46. https://doi.org/10.1177/001316446002000104.

[43] D.H. Douglas, T.K. Peucker, *Algorithms For The Reduction Of The Number Of Points Required To Represent A Digitized Line Or Its Caricature*, **Cartographica: The International Journal for Geographic Information and Geovisualization**, **10**, 1973, pp. 112-122. https://doi.org/10.3138/FM57-6770-U75U-7727.

[44] J.R. Landis, G.G. Koch, *The Measurement of Observer Agreement for Categorical Data*, **Biometrics**, **33**(1), 1977, pp. 159-174. https://doi.org/10.2307/2529310.

[45] J.L. Fleiss, B. Levin, M.C. Paik, **Statistical Methods for Rates and Proportions,** Wiley, 2003. https://doi.org/10.1002/0471445428.

[46] D. V. Cicchetti, F. Volkmar, S.S. Sparrow, D. Cohen, J. Fermanian, B.P. Rourke, *Assessing the reliability of clinical scales when the data have both nominal and ordinal features: Proposed guidelines for neuropsychological assessments*, **Journal of Clinical and Experimental Neuropsychology**, **14**, 1992, pp. 673-686. https://doi.org/10.1080/01688639208402855.

[47] B.L. Welch, *The generalization of 'Student's' problem when several different population varlances are involved*, **Biometrika**, **34**, 1947, pp. 28–35. https://doi.org/10.1093/biomet/34.1-2.28.

[48] H. Levene, *Robust tests for equality of variances*, in: I. Olkin (Ed.), **Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling**, Stanford University Press, Stanford, California, 1960, pp. 278-292.

[49] T. Chrobak, M. Lupa, S. Szombara, D. Dejniak, *The use of cartographic control points in the harmonization and revision of MRDBs*, **Geocarto International**, **34**, 2019, pp. 260-275. https://doi.org/10.1080/10106049.2017.1386721.

[50] Y. Liu, W. Li, *A New Algorithms of Stroke Generation Considering Geometric and Structural Properties of Road Network*, **ISPRS International Journal of Geo-Information**, **8**(7), 2019, Article Number: 304. https://doi.org/10.3390/ijgi8070304.

[51] B.J. Kronenfeld, L. V. Stanislawski, B.P. Buttenfield, T. Brockmeyer, *Simplification of polylines by segment collapse: minimizing areal displacement while preserving area*, **International Journal of Cartography**, **6**(1), 2020, pp. 22-46. https://doi.org/10.1080/23729333.2019.1631535.

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