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FEATURES OF INVENTORY OF GREEN PLANTINGS BY AUTOMATED TERRESTRIAL LASER SCANNING METHODS

The aim of this work is to investigate the process of obtaining necessary information about the metric parameters of small-area arrays, linearly arranged and individual green plantings on predominantly urbanized territories, and to apply the results of data processing in the compilation of topographic and special maps from the corresponding scanning materials. Methodology. For this purpose, terrestrial laser scanning methods, dynamic laser scanning as a data source for tree-level mapping of the territory, and as an information base for filling in the respective cadastres are subject to research. The possibilities of using data from these methods to obtain information about green plantings using modern software tools have been explored. Based on terrestrial laser scanning data performed in accordance with the requirements of regulatory spatial reference documents, data processing of terrestrial laser scanning was carried out using automated methods, namely the Terrasolid software suite. The need for more than 40% coverage of the tree trunk with a point cloud obtained from laser scanning to eliminate possible errors in determining the relevant parameters due to the heterogeneity of the structure of different tree trunks has been confirmed. Preliminary processing of scanning materials was carried out using FARO Scene 2020 software. Scientific novelty and practical significance. An experiment was conducted to analyze the creation of both a plan-altitude and an information base regarding green plantings on selected objects within the Zakarpattia region. The process of collecting data on green plantings was improved by using terrestrial laser scanning and partial GNSS measurements, instead of traditional topographic-geodetic methods. A table containing information on green planting data has been created for the studied objects' territory. Automated methods were used to gather this information, including details about their location in the adopted coordinate system and the trunk diameter at a height of 1.3 meters.

Key words: terrestrial laser scanning; automated methods; tree trunk; diameter; digital surface models; inventory of green plantings.

Introduction

Information about green infrastructure objects is one of the components of the life of territories, especially urbanized areas. Inventory materials of green plantings are integral to maintaining various cadastres, including components of large-scale topographic surveys. Classical inventory of green plantings requires a significant amount of time, and in some cases, this process can be expensive or imprecise compared to modern methods of populating various cadastres.

Inventory of green plantings conducted following the "Instruction on the Technical Inventory of Green Plantings" [Verkhovna Rada of Ukraine, 2001] in cities and urban-type settlements of Ukraine every five years from April to October. It includes: determining the total area occupied by green infrastructure objects, including trees, shrubs, flower beds, lawns, paths, etc.; determining the number of trees and shrubs by types of plantings, species, age, diameter at a height of 1.3 meters of tree trunks, and their maintenance status; determining the overall and individual plot values.

Requirements for the technology of measuring green plantings in Ukraine are currently not regulated, except for the requirements provided by the "Instruction on Topographic Surveying at Scales 1:5000, 1:2000, 1:1000, and 1:500" [Verkhovna Rada of Ukraine, 1998].

Research on the use of data related to green plant inventory, as well as the maintenance of different cadastres, has been conducted using various technologies. They include digital aerial photography, static and dynamic terrestrial laser scanning, terrestrial photogrammetry, fisheye effect photogrammetry (FEP) through specialized cameras, virtual reality devices (MRDC) [Fol et al., 2023], high-speed personal laser scanning (PLS), and simultaneous localization and mapping technology (SLAM) [Tockner et al., 2022]. Additionally, consumer cameras and smartphones with specialized apps have also been utilized for this purpose [Gollob et al., 2021].

In the modern world, various types of scanning are used for not only modeling and preserving data about important historical and architectural objects but also as a means of obtaining information about the surrounding environment, as a source of remote sensing data (RS).

Point clouds are quite an effective tool for inventory as they allow for the rapid and accurate creation of a 3D model of an object. They enable tasks such as measuring the height and volume of the object and obtaining precise coordinates of its elements. Moreover, the use of point clouds eliminates the possibility of gross errors that can occur during manual measurements.

Point clouds obtained from terrestrial laser scanning can be used to create accurate 3D models of the trunks of green plantings. This allows for the determination of the diameter, height, and shape of trunks with an accuracy of a few millimeters.

Additionally, point clouds can be used to determine the density and placement of green plantings on the terrain, enabling the monitoring of changes in vegetation cover over time.

The application of automated technologies in the inventory of green plantings has been extensively researched over the past decade. There is a wide range of studies on the automation of these processes worldwide, some of which are discussed in works by [Kalvoda et al., 2020; Kuželka et al., 2021; et al., 2020; Wang et al., 2019; Tockner et al., 2022; Witzmann et al., 2022]. In Ukraine, this issue has also been addressed, including the development of conceptual principles for automating the monitoring of urban green plantings [Yalova, 2019]. In the work [Rohovskyi, 2021] highlights the issue of the quality of the inventory of green spaces in Ukraine

Research has been conducted on the optimization of terrestial laser scanning for inventorying green spaces [Abegg et al., 2017; Vash et al. 2022].

Some of the already published solutions for green planting inventory involve the development of software that utilizes data from various remote sensing methods, including the use of artificial intelligence. Some of these solutions have been successfully tested in large-scale green planting inventory, such as the MTLS-AIDFOREST method [Serrano et al., 2022]. This software is capable of autonomously determining the characteristics of forest plantings in real-time using a mobile laser scanning system based on virtual reality helmet technology [Li et al., 2023].

The methods and software mentioned above are not exhaustive. Most modern geoinformation resources, with the right settings, allow for the automation of certain processes when identifying green plantings. For instance, works by [Ritter et al., 2017; Tockner et al., 2022] have utilized R software for research purposes.

In a usage study [Wilkes et al., 2022], trees were segmented with a match factor of 82%.

According to the work [Liang et al, 2018]? TLS-based approaches can provide estimates of DBH and stem curves with an accuracy of 1–2 cm, which is close to what is required in practical applications such as inventory. Five directly measured criteria from plot- and tree-level TLS data were also identified. They include diameter at breast height (1.3 m, DBH), tree height, tree position, trunk curve (trunk diameter as a function of height), and a digital terrain model. (DTM).

According to the work [Trochta et al, 2017], the LSR method provided slightly higher values than measurements with a conventional caliper – 1.17 cm.

In pilot studies [Maas et al, 2008], more than 97% of trees were detected correctly, and DBH could be determined with an accuracy of about 1.8 cm.

The work [Liang et al, 2016] structured the relationship between the average scanning distance, the stem density and the errors of estimating the height at chest level, which ranged from 0.2 cm to 7.6 cm with different approaches and the estimated errors from 0.1 to 1 .5 meters when determining heights.

Objective

This work aims to investigate automated methods for obtaining necessary information about the location of trees and the diameter of their trunks at breast height when conducting an inventory of green plantings using terrestrial laser scanning of the territory and comparing them with analog methods.

Research Methodology

According to [Semko, 2015], for the stated objectives, the TerraScan software from the Finnish company Terrasolid can be used, along with specific functionalities within ArcGIS. According to the "TerraScan User Guide," aerial and mobile data can be used to establish a foundation for tree inventory, providing XYZ coordinates as well as information about trunk width and height through a fully automated process. By utilizing additional sensor data, even more information can be obtained.

The scheme of the study is shown in Fig. 1.

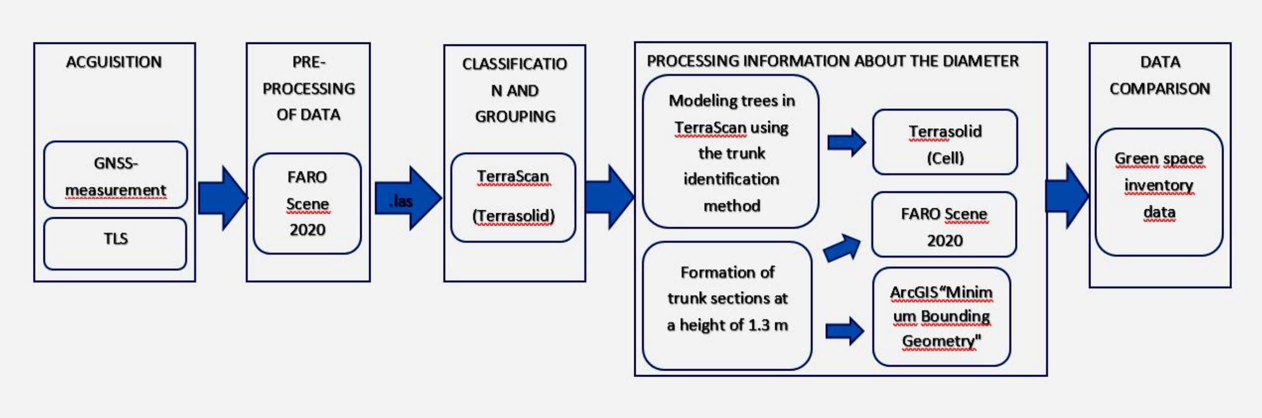


Fig. 1. Structural block diagram of the study

When using terrestrial laser scanning devices such as FARO FOCUS S150, to conduct an inventory of green plantings as suggested by [Vash et al., 2022], one of the main challenges is the limited accuracy in scanning vegetation, especially tree branches and leaves.This limitation can lead to inaccuracies in determining their quantity and volume. Furthermore, the scanning process can be complicated by the presence of other objects, such as buildings, vehicles, people, etc., which can impact the accuracy and completeness of the acquired data. Additional measurements may also be required to determine other tree parameters, such as wood volume.

Research Findings

Data collection and processing.

In the first stage, we collected and analyzed data from terrestrial laser scanning and GNSS measurements were. GNSS observation was conducted for high-quality geospatial reference of ground laser scanning materials.

Terrestrial laser scanning materials were initially analyzed using FARO Scene 2020 software. Point clouds were processed following the principles and schemes given in the work [Stoli, 2014]. In the future, point clouds at all stages of the study will be processed in the .las format.

To classify data from the selected laser scanning object, T. Masaryk Square in Uzhhorod [Vash, 2022], TerraScan software from the Finnish company Terrasolid was utilized according to recommendations [Semko, 2015], using the license of UZHNU with available modules TerraMatch UAV, TerraModeler UAV, TerraScan UAV.

Work with FARO Scene 2020 software and TerraMatch UAV, TerraModeler UAV, and TerraScan UAV was performed based on the licensee - UZHNU.

The data classification process in this software offers a wide range of data filtering settings, with key settings consolidated in the "Wizard" section, which are used to create typical projects from environmental datasets.

In particular, this section includes the "Classify ground" function, from which, following [Semko, 2015], data classification can begin to identify points belonging to the ground class (Ground).

Grouped data from the classes "High vegetation" and "Tree," which can be used for further research, are illustrated in Fig. 2.

The processing of terrestrial laser data commenced with the point cloud filtering. This included the removal of overlapping surface portions in the point cloud, smoothing, noise reduction, and the elimination of distant, isolated, and erroneous points located either in the air or below the ground surface. These functions were executed with customized settings to obtain the most accurate and reliable data for subsequent classification. The resulting data, with the point cloud normalized, is presented in Table 1.

In the following steps, for convenience, two classes were retained: "Ground" and "Tree." Data from the "High vegetation" class were transferred to the "Tree" class (see Fig. 3). After normalizing the point cloud, the filtering of the "Tree" class was conducted at a height of 1.3 meters above the ground surface in several stages.

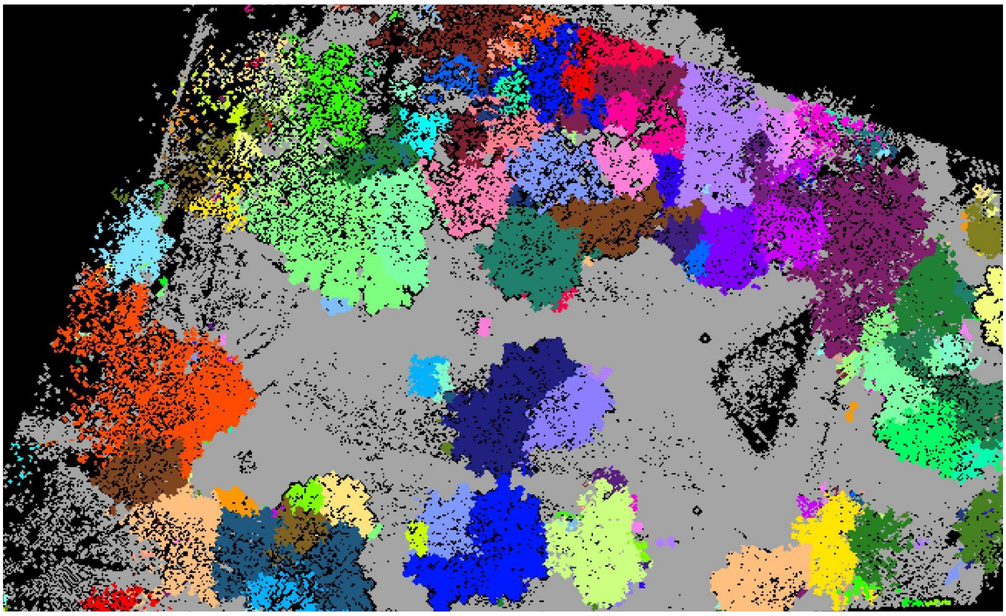


Fig. 2. Grouped data of the obtained classes High Vegetation and Tree

Table 1

Bringing the point cloud to a normalized state

Object class	Number of points	Min. Z	Max. Z
All points	15 798 215	116.38	161.96
Ground	265 467	116.38	118.14
Low vegetation	8 628 237	116.42	138.44
Medium vegetation	46 975	116.86	119.92
High vegetation	1 921 028	116.91	146.25
Building roof	475	120.19	121.11
Object class	Number of points	Min. Z	Max. Z
Low point	7	135.98	161.96
Vegetation	439 942	116.84	141.44
Tree	2 446 466	116.94	141.2
Car	42 369	117.03	119.6
Pole	1 249	120.18	134.32

The first step involved isolating and extracting points located at a height of 129 to 131 cm above the ground, following the recommendations outlined in the work by [Semko, 2015]. These points were then organized into sets of point clouds for further processing in the form of individual cross-sections of tree trunks (see Fig. 4). The obtained data allowed for the manual determination of the key parameters sought.

***Obtaining information about green spaces*.**

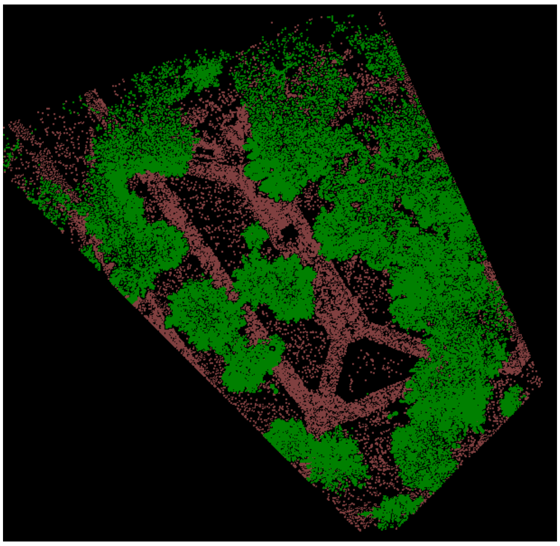
The further analysis included the construction of tree trunk circles around the data. Implementing this process manually can be time-consuming. Therefore, for determining tree diameters, algorithms for circle approximation were utilized in an arithmetic manner, following the approach suggested by [Strzeliński, 2008].

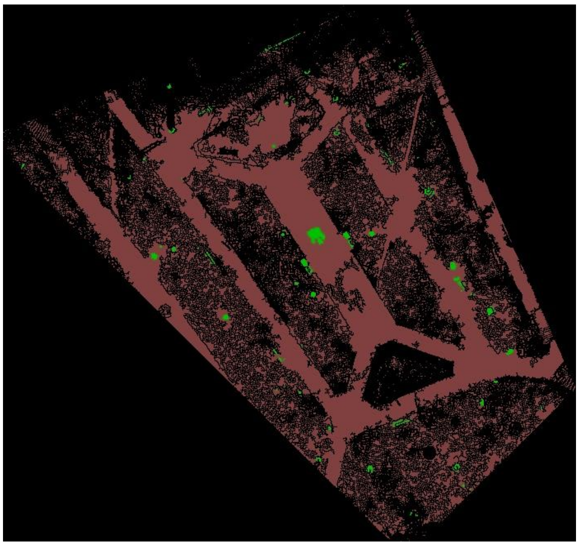
To implement this method, modeling tools like "Cell" in the Terrasolid software were employed. Additionally, the "Minimum Bounding Geometry" tool in ArcGIS software was used for comparison.

As we can observe from Fig. 5, to obtain high-quality data, it is necessary to filter the point cloud not only at a height of 1.3 meters but also at other heights. The process for identifying trees is similar to the work presented by [Serrano et al., 2022]. The current version of the AID-FOREST software is optimized for estimating the total volume of individual tree trunks (single-trunk branching) but not for multiple trunks or branches (multi-trunk branching).

According to the [TerraScan User Guide], the modeling of the positioning of green plantings was carried out using available typical models such as Betula pendula and Picea abies for the stem identification method (see Fig. 6). This approach was adopted because the highest point identification method, which is more suitable for green planting identification when using point clouds from airborne lidar data, tends to produce too many erroneous values.

As a result of the processing, data was obtained indicating the coordinates of the tree trunk, its height and the diameter of the trunk at a height of 1.3 meters.





Figs. 3, 4. The obtained results of the point cloud after its classification

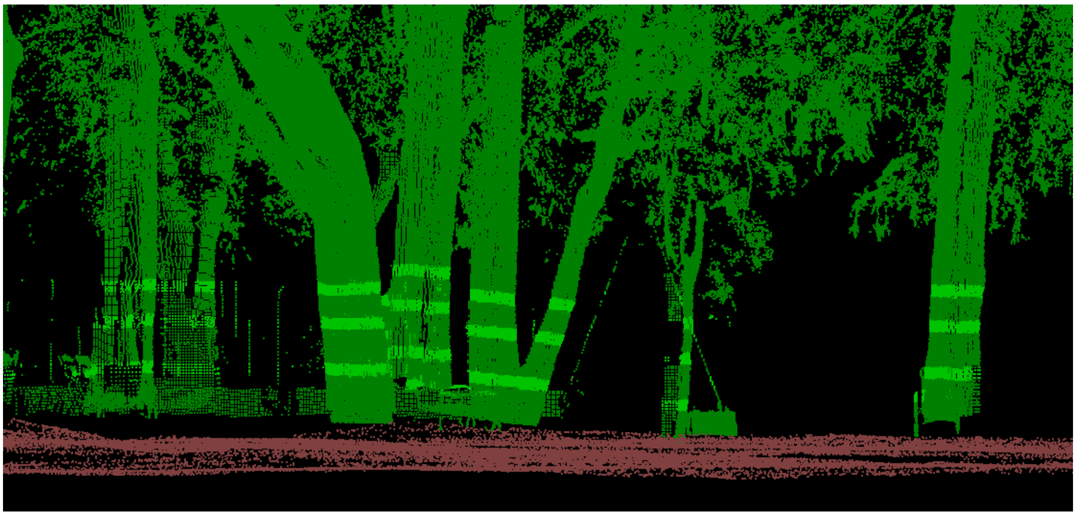


Fig. 5. Filtering of the point cloud with defined cross-sections

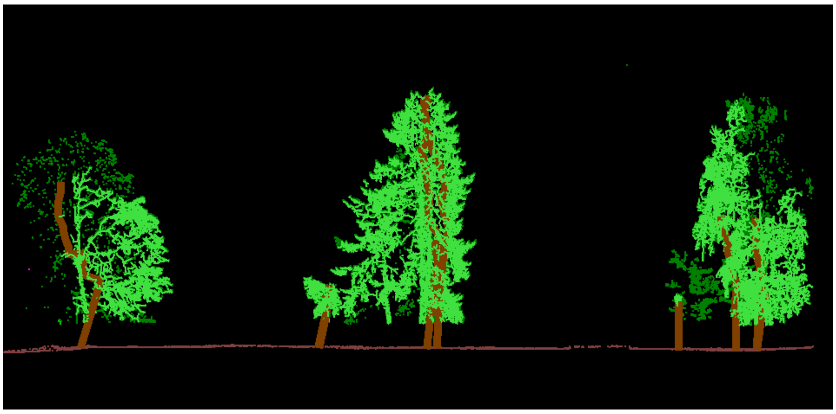


Fig. 6. Graphical representation of the object modeling process in TerraScan software

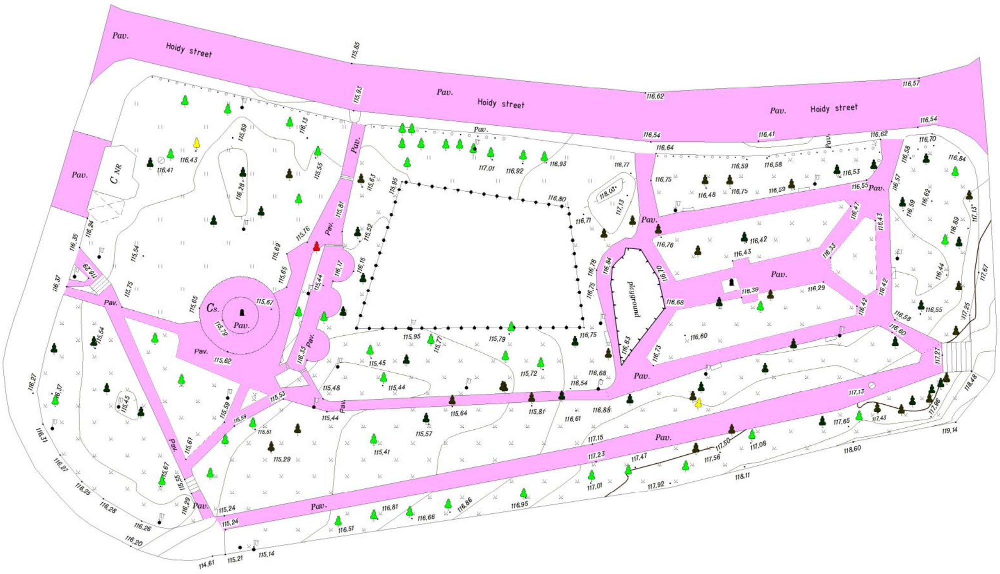


Fig. 7. Materials of the inventory of green spaces in T. Masaryk Park in Uzhhorod

Data comparison. The obtained data table with coordinates of tree trunks, their height, and trunk diameter at a height of 1.3 meters was then compared with the materials from the traditional greenery inventory [Vash, 2022], as shown in Fig.7.

The difference in trunk diameter at a height of 1.3 meters ranges from -2.3 cm to 3.4 cm_with a correlation coefficient of 96%, confirming the results [Liang et al, 2016; Trochta et al, 2017; Liang et al., 2018; Wilkes et al., 2022].

Scientific novelty and practical significance

The scientific novelty of this research lies in the possibility of creating a plan-height basis and an information database regarding green plantings on selected objects in the territory of the Zakarpattia region.

The study has improved the technology for obtaining data on green plantings without relying on classical topographic and geodetic methods, by utilizing terrestrial laser scanning and partial GNSS measurements.

The practical significance of the obtained results is the demonstration of the feasibility of using automated technologies for acquiring data about green plantings and their subsequent application in creating (updating) planimetric and cartographic materials and maintaining sectoral cadastres, including urban planning [Verkhovna Rada of Ukraine, 2011].

Conclusions

Accurate tree segmentation is considered an important functionality of automated 3D point cloud analysis and serves as a prerequisite for measuring the characteristics of individual trees.

Based on geospatial referenced data, automated Terrasolid processing was done on laser scanning data acquired according to regulatory requirements.

As a result, on the territory of the research object, a data table of green plants was created using automated methods with information about their location in the accepted coordinate system and the diameter of the trunk at a height of 1.3 meters.

The data collected was compared to the inventory records of green spaces in T. Masaryk Square in Uzhhorod. It was determined that there is a need to verify the data obtained by automated methods, especially when there are multi-stem branches present..

The study confirmed that to avoid errors in determining relevant indicators due to the heterogeneous structure of different tree trunks, it is necessary to have more than 40% coverage of the tree trunk with a cloud of points obtained from laser scanning.Some software solutions continue to improve their automated methods for obtaining information about green spaces from point clouds.

It is worth noting that efforts are being made to enhance the automation of acquiring precise and reliable information from terrestrial laser scanning materials. To achieve this, modern tools and techniques are utilized to collect and process data, especially with regards to obtaining information on the type and condition of plantations. Further research is required for determining the centers of trees when there is incomplete cloud coverage of points on the lower part of the tree trunk and at chest level. This is particularly important in cases where the trunk branches into two or more trunks at chest level.

REFERENCES

Abegg, M., Kükenbrink, D., Zell, J., Schaepman, M. E., & Morsdorf, F. (2017). Terrestrial laser scanning for forest inventories – tree diameter distribution and scanner location impact on occlusion. *Forests*, 8(6), 184.137-179. https://doi.org/10.3390/f8060184

Fol C. R., Kükenbrink D., Rehush N., Murtiyoso A., Griess V. C. (2023). Evaluating state-of-the-art 3D scanning methods for stem-level biodiversity inventories in forests. International Journal of Applied Earth Observation and Geoinformation, 122, 103396, https://doi.org/10.1016/j.jag.2023.103396

Gollob, C., Ritter, T., Kraßnitzer, R., Tockner, A., & Nothdurft, A. (2021). Measurement of forest inventory parameters with Apple iPad pro and integrated LiDAR technology. Remote Sensing, 13(16), 3129. https://doi.org/10.3390/rs13163129

Kalvoda P., Nosek J, Kuruc M., Volarik T. and Kalvodova P. (2020) Accuracy Evaluation and Comparison of Mobile Laser Scanning and Mobile Photogrammetry Data. 2020. IOP Conference Series: Earth and Environmental Science, Volume 609. https://doi.org/10.1088/1755-1315/609/1/012091

Kuželka K., Surový P. (2021) Mathematically optimized trajectory for terrestrial close-range photogrammetric 3D reconstruction of forest stands. ISPRS Journal of Photogrammetry and Remote Sensing, 178, 259-281. https://doi.org/10.1016/j.isprsjprs.2021.06.013

Li J., Yang B., Yang Y., Zhao X., Liao Y., Zhu N., Dai W., Liu R., Chen R., Dong Z. (2023). Real-time automated forest field inventory using a compact low-cost helmet-based laser scanning system. Int. J. Appl. Earth Obs. Geoinf., 118, 103299, https://doi.org/10.1016/j.jag.2023.103299

Liang, X., Hyyppä, J., Kaartinen, H., Lehtomäki, M., Pyörälä, J., Pfeifer, N., ... & Wang, Y. (2018). International benchmarking of terrestrial laser scanning approaches for forest inventories. ISPRS journal of photogrammetry and remote sensing, 144, 137-179. https://doi.org/10.1016/j.isprsjprs.2018.06.021

Liang, X., Kankare, V., Hyyppä, J., Wang, Y., Kukko, A., Haggrén, H., ... & Vastaranta, M. (2016). Terrestrial laser scanning in forest inventories. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 63-77.

Maas, H. G., Bienert, A., Scheller, S., & Keane, E. (2008). Automatic forest inventory parameter determination from terrestrial laser scanner data. International journal of remote sensing, 29(5), 1579-1593.

Ritter, T., Schwarz, M., Tockner, A., Leisch, F., & Nothdurft, A. (2017). Automatic mapping of forest stands based on three-dimensional point clouds derived from terrestrial laser-scanning. Forests, 8(8), 265 https://doi.org/10.3390/f8080265

Rogovskyi, S. V., Zhikhareva, K. V., Oleshko, O. G., Strutynska, Yu. V., & Kolotnytska, A. V. (2021). Modern problems of plant inventory in urban plantations and experience in solving them. *Scientific Bulletin of the National Forestry University of Ukraine:* (in Ukrainian) https://rep.btsau.edu.ua/handle/BNAU/7163

Semko, I. D. (2015). The method of determining the above-ground phytomass of a Scots pine stand based on the materials of aerial lidar surveying (in Ukrainian): https://www.casre.kiev.ua/images/files/paper-semko.pdf

Serrano, F. L., Rubio, E., Morote, F. G., Abellán, M. A., Córdoba, M. P., Saucedo, F. G., ... & González, J. G. (2022). Artificial intelligence-based software (AID-FOREST) for tree detection: A new framework for fast and accurate forest inventorying using LiDAR point clouds. International Journal of Applied Earth Observation and Geoinformation, 113, 103014.. 113.2022. https://doi.org/10.1016/j.jag.2022.103014.

Stoli, S., & Rex, D. (2014). Applications of 3D Laser Scanning in a Production Environment.

Strzeliński P., Jagodziński A. M., Wencel A., Zawiła Niedźwiecki T. (2008). Szacowanie zasobów węgla w lasach z wykorzystaniem technik geomatycznych. Techniki geomatyczne w inwentaryzacji lasu — potrzeby i możliwości. Warszawa: Wyd. SGGW, 114–125.

TerraScan User Guide URL: https://www.terrasolid.com/guides/tscan/crtrees.html

Tockner, A., Gollob, C., Kraßnitzer, R., Ritter, T., & Nothdurft, A. (2022). Automatic tree crown segmentation using dense forest point clouds from Personal Laser Scanning (PLS). International Journal of Applied Earth Observation and Geoinformation, 114, 103025. https://doi.org/10.1016/j.jag.2022.103025

Trochta, J., Krůček, M., Vrška, T., & Král, K. (2017). 3D Forest: An application for descriptions of three-dimensional forest structures using terrestrial LiDAR. PloS one, 12(5), e0176871. https://doi.org/10.1371/journal.pone.0176871

Vash, Y., Hubar, Yu. (2022) The method of optimizing measurements with a ground laser scanner of the green plants of T. Masarik park in Uzhgorod. In International Conference of Young Professionals, GeoTerrace 2022, 1, 1-5. European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.2022590048

Vash, Y., Gubar, Yu, Kalynych, I. & Chetverikov, B. (2022). Inventory of horticultural facilities of T. Masaryk Square in Uzhgorod with the use of TLS. (in Ukrainian) https://doi.org/10.33841/1819-1339-2-44-121-129

Verkhovna Rada of Ukraine (1998). On the approval of the Instructions for topographical surveying at scales of 1: 5000, 1: 2000, 1: 1000 and 1: 500 (DSTU 2.04-02-98). Ukrgeodeskartography; Order No. 56 of April 9 (in Ukrainian) https://zakon.rada.gov.ua/laws/show/z0393-98

Verkhovna Rada of Ukraine (2001). On the approval of the Instructions for the inventory of green spaces in populated areas of Ukraine State Committee for Construction, Architecture and Housing Policy of Ukraine Order of December 24 No. 226 (in Ukrainian) https://zakon.rada.gov.ua/laws/show/z0182-02#Text

Verkhovna Rada of Ukraine (2011). Cabinet of Ministers of Ukraine Decree No. 559 of May 25 on the urban planning cadastre (in Ukrainian) https://zakon.rada.gov.ua/laws/show/559-2011-%D0%BF#Text

Wang, Y., Pyörälä, J., Liang, X., Lehtomäki, M., Kukko, A., Yu, X., ... & Hyyppä, J. (2019). In situ biomass estimation at tree and plot levels: What did data record and what did algorithms derive from terrestrial and aerial point clouds in boreal forest. Remote Sensing of Environment, 232, 111309. https://doi.org/10.1016/j.rse.2019.111309

Wilkes, P., Disney, M., Armston, J., Bartholomeus, H., Bentley, L., Brede, B., ... & Yang, W. (2022). TLS2trees: A scalable tree segmentation pipeline for TLS data. Methods in Ecology and Evolution. https://doi.org/10.1101/2022.12.07.518693

Witzmann, S., Matitz, L., Gollob, C., Ritter, T., Kraßnitzer, R., Tockner, A., ... & Nothdurft, A. (2022). Accuracy and precision of stem cross-section modeling in 3D point clouds from TLS and caliper measurements for basal area estimation. Remote Sensing, 14(8), 1923. https://doi.org/10.3390/rs14081923

Yalova, K. (2019). Conceptual propositions of the city's green plantations monitoring automation *Computer-integrated technologies: education, science, production*, (35), 112-116. (in Ukrainian). http://cit-journal.com.ua/index.php/cit/article/view/84

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ОСОБЛИВОСТІ ІНВЕНТАРИЗАЦІЇ ЗЕЛЕНИХ НАСАДЖЕНЬ АВТОМАТИЗОВАНИМИ МЕТОДАМИ НАЗЕМНОГО ЛАЗЕРНОГО СКАНУВАННЯ

Мета цієї роботи – дослідження процесу отримання необхідної інформації про метричні показники невеликих за площею масивів, лінійно розташованих та поодиноких зелених насаджень на переважно урбанізованих територіях та застосування результатів опрацювання даних при складанні топографічних та спеціальних карт з відповідних матеріалів сканування території. Методика. З цією метою дослідженню підлягають методи наземного лазерного сканування, динамічного лазерного сканування як джерело даних для подеревної зйомки території та як інформаційна база для наповнення відповідних кадастрів. Досліджено можливості використання даних методів для отримання інформації про зелені насадження з використанням сучасних програмних засобів. На основі даних наземного лазерного сканування, виконаного відповідно до вимог нормативних документів з геопросторовою прив'язкою, проведено опрацювання даних наземного лазерного сканування з використанням автоматизованих методів а саме програмного комплексу Terrasolid. Підтверджено необхідність наявності більше 40% покриття стовбура дерева хмарою точок, отриманою з лазерного сканування для усунення можливих помилок при визначенні відповідних показників у зв'язку з неоднорідністю будови різних стовбурів дерев. Попереднє опрацювання матеріалів сканування виконано за допомогою програмного забезпечення FARO Scene 2020. Наукова новизна та практична значущість. Проведено експериментальний аналіз створення планово-висотної основи та інформаційної бази про зелені насадження на обраних об'єктах на території Закарпатської області. Удосконалено технологію отримання даних про зелені насадження, без використання класичних методів топографо-геодезичних робіт, із застосуванням наземного лазерного сканування та частково GNSS вимірювань. В результаті на території досліджуваних об'єктів автоматизованими методами створено таблицю даних зелених насаджень з інформацією про їх розташування у прийнятій системі координат та діаметром стовбура на висоті 1.3 метра.

Ключові слова: наземне лазерне сканування; автоматизовані методи; стовбур дерева; діаметр; цифрові моделі поверхні; інвентаризація зелених насаджень.

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