Generating a three-dimensional measuring scene for the forest sector as based on modern geodetic technologies

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Abstract. Modern geodetic technologies of gathering three-dimensional spatial data incorporate terrestrial laser scanning and aerial photo survey from unmanned aerial vehicles. The combination of these technologies and joint result of survey provide the data of 3D point model and accurate information on trunks and crowns of individual trees. The paper examines the experiment with the application of method of formation of 3D measuring scene in the form of dense cloud of points combining the results of terrestrial laser scanning and materials of photogrammetric processing of UAV-provided data. The method eliminates basic shortcomings of each technology, enhances their advantages, and opens the way to the compilation of more representative 3D measuring scenes. A specific advantage of the method is the outcropping of detailed information on the form, size and condition of individual tree crowns. This option finds a practical application in landscape evaluation and design, remote measuring of trunk parameters excluding the felling of model trees for the compilation of regional timber account tables. The closest perspectives of method development are related to increasing the accuracy of combined survey by specifying flight missions and working with the light regime under forest canopy.

1. Introduction

The development of modern devices of active remote sensing including the systems of laser scanning opens new opportunities for the resolution of applied tasks in the forest sector of economy. At present, the main advantage of aerial and terrestrial laser scanners is an increased spatial precision and specificity of generated dense cloud of points. An active development of approaches and algorithms of processing of scanning results increases the attraction of this technology. In addition, the ways of combines processing of the results of laser scanning with more traditional technologies, such as aerial photography, are studied actively.

In many countries, a great progress was achieved in the studies of application of laser scanning and other modern technologies to solve the tasks of the forest sector based on the approaches to the modelling of 3D scenes of forest plots [1]; the evaluation of forest damage on the basis of data obtained from aerial laser scanners gets elaborated [1]; forest inventory characteristics and biomass are determined [2-4]; descriptions of three-dimensional forest structures were made [5].

The majority of current systems of land resources management is based on the two-dimensional way of data representation and can not adjust to the diversity of complex situations emerging from the reality of contemporary world [6,7]. In addition, current society needs in the stable environment and the mind-
set in the scale of complete lifetime of an object or phenomenon stimulates the integration of independent systems with autonomous databases and methodologies related to various aspects of a life cycle of spatial development of human managing territories (SDC). The standards of models of land resources management are elaborated and implemented serving as a baseline structure of three-dimensional system of land resources management [8,9]. The opportunity of computer assisted classification of dense cloud of points is studies in order to distinguish objects, for example, single trees or their parts [10].

The Association of European Public Mapping Agencies studied the cost-benefit ratio of using the technologies based on the 3D geoinformation for the solution of engineering tasks, including those in the forest sector, and came to the conclusion that it provided serious economic advantages [11], down to the 1:3 cost-benefit ratio.

In this work, we examine the possibility of creating 3D measuring scenes of forested territories based on a combined implication of terrestrial laser scanning and high-resolution aerial photos obtained from an unmanned aerial vehicle (UAV). This approach makes it possible to eliminate major disadvantages of each technology and enhance their good points and opens the way to providing more representative 3D measuring scenes, which in future can be used to meet the challenges in the forest sector.

2. Materials and methods

Field survey was made at the territory of the Arboretum of the Mytishchi Branch (55°55.6' N, 37°47.8' E). This is an easily accessible compact object with the area of 1.65 ha and high diversity of tree species. The arboretum was created more than 60 years ago, has the shape of multistorey stand with the average tree height of ca. 24 m and stand density suitable for the use of terrestrial laser scanner.

The aerial survey of the arboretum was conducted using the unmanned aerial vehicle Phantom 4 Advanced (Производитель, Страна) equipped with the embedded camera. The camera has the FC6310 code according to the universal classifier, the size of matrix pixel is 2.61 by 2.61 microns, focus distance is 8.8 mm, and matrix size is 4000 by 36,000 pixels. The camera allowed us to obtain the data with the characteristics, which are acceptable for the photogrammetric processing with a high degree of computer assistance (SFM - Structure From Motion).

The flight mission was shaped with the help of Drone Deploy (Производитель, Страна) flight controller in the way to guarantee the aerial survey data with the ground sample distance (GSD) of at least 2 cm pixel\(^{-1}\) and the overlapping of at least 85%. The survey was conducted in early autumn (September 5-20, 2020). Total 128 pictures were obtained; one of them was rejected because of excess smearing.

Calculated precision of point coordinates determination in the zones of aerial photos overlapping is expressed and the mean square error and depends of the characteristics of survey system and flight mission. It was calculated according to formulas (1)-(3) and constitutes 1.5 cm in the plan and 4 cm in the altitude [12]:

\[
m_x = \frac{Z}{f} p_x
\]

\[
m_y = \frac{Z}{f} p_y
\]

\[
m_z = \frac{Z}{f} p_z
\]

where \(m_x, m_y,\) and \(m_z\) are root mean square errors in the plan and altitude, respectively, \(m; z\) is altitude, \(m; f\) is the focus distance, mm; \(p_x, p_y,\) and \(p_z\) are measurement errors, mm.
Data processing was run in the Agisoft Photoscan software with a high degree of computer assistance, which made it possible to reduce significantly human participation. This approach is optimal for the processing of big volumes of aerial survey data and generally demands less skills of a processing engineer. Modern digital tools help to provide the computer assistance for both monocular and stereoscopic measurements in the process of photogrammetric image processing.

Considering that the main processing goal was to provide the most representative information about tree crowns and trunks (whereas possible), the compilation of dense cloud of points was conducted with maximum quality setting and mild filtration of depth maps. The results were exported to the \textit{.las} format to be further joined to the results of terrestrial laser scanning. In addition, the orthophotoplan was produced for the surveyed territory.

The three-dimension ground spatial information was provided by the ground survey using the Leica BLK360 scanner (Производитель, Страна). The challenge we met when using this scanner in our experiment was the need in providing the visibility of linking points (marks) from neighbouring scanning stations. Moreover, as compared to the interior scanning, it was necessary to shorten the steps (basis lengths between neighbouring scanning stations) in order to facilitate the registration of neighbouring clouds of points. To register neighbouring scans directly, we used special marks placed on earth surface or fixed on trunks or other objects. The images of linking marks, contrasting with the general background, made it possible to register clouds of points under field conditions. Embedded algorithms of automatic registration proved to be unacceptable under the conditions of this experiment.

The procedure of joining two clouds of points obtained from different sources with the help of character points was carried out manually using the open-access tool Cloud Compare, with controlled precision.

3. Results
The processing of aerial survey images provided us with the dense cloud of 389 mln points (figure 1a) and the orthophotoplan with the GSD of 1.85 cm pixel\(^{-1}\) (figure 1b).

![Figure 1. Result of photogrammetric processing of aerial survey from an unmanned aerial vehicle represented as a dense cloud of points (a) and orthophotoplan (b).](image)

Under the conditions of close forest canopy, a highly computer-assisted photogrammetric processing can be unsuccessful because of excessive divergence of corresponding locations. This is due to the specificity of representation of high-altitude objects on the images obtained in the central projection and principles of automatic image processing.

At present, digital photogrammetric systems, including the Agisoft Photoscan programme package used in the experiment, apply the method of computer-assisted identification of corresponding points. The process is based on the comparison of pixels values of fragments of raster digital images with identic size. In our experiment, we applied the correlation method of measuring of corresponding points on the images in the overlapping zones. The idea is that a fragment of a given size is constructed for a definite measured point on one image. Then this fragment is treated as a sliding standard window and run along the overlap zone with the one-pixel step in order to compare and search a corresponding location on the
other image. The search comprises the comparison of corresponding pixel brightness within the standard mask. If brightness values match reliably, the identical image point is assumed to be determined. The reliability is described by the coefficient of correlation, as it is less affected by noises.

Successful processing was possible due to a sufficient number of contours at earth surface level suitable for an unambiguous automatic recognition in the overlap zones. In a real forest, these contours can be represented by stubs, spots of bare soil, roads, etc. Figure 2c represents the result of joining two clouds of points from different sources: UAV aerial survey (figure 2a) and terrestrial laser scanning (figure 2b) using common characteristic points.

![Figure 2](image-url)  

**Figure 2.** Joining two clouds of points from different sources: UAV aerial survey (a), terrestrial laser scanning (b), and the resulting image (c).

The open-source Cloud Compare software was used to join dense clouds of points obtained from different sources. The align and merge scalar fields tools were run, their essence being to identify the images of point series in two clouds. After selecting the points, the program calculates the transformation parameters and presents them as a matrix, then it calculates the root mean square error (RMS) of combination of the two clouds of points. In this study, the cloud from the aerial photo survey (APS) data was taken as the reference one, while the data from the terrestrial laser scanning (TLS) was transformed. After the transformation, the clouds were saved as a joint cloud in .las format using the merge scalar fields procedure.

The programme package creates a report with the results of cloud joining represented as the values of the matrix of scalar fields transformation and root mean square error, which was 0.07 in this experiment (figure 3). The transformation took less than 10 minutes.

The resulting three-dimension scene can be exported to any actual format of dense cloud representation and integrated to the GIS or 3D viewer for further treatment. The data on trunk form and allocation, which are inaccessible from an aerial photo, are added from laser scanning. Vice versa, the inaccessibility of tree crowns for terrestrial laser scanning is compensated by aerial survey data.

The resulting modified dense cloud can be analysed in special software. The point cloud can be further segmented into separate trees in order to get the desired information about tree attributes. Program algorithm is based on searching neighboring voxels according to the chosen number of descriptors: Principal Component Analysis (PCA), slope, intensity, and PCA-slope multiplication and etc. If free voxels or elements have the descriptor value up to the threshold they are incorporated in a tree model.

The studies of the created scene indicated the possibility of using embedded tools and utilities of various software, for example, AutoDesk Recap Pro, 3D Forest and others, to measure trees characteristics such as height and diameter.
The point models of trees obtained from the APS data and combined APS and TLS data are represented on the figures 4a and 4b, respectively. The white part of the crown on the figure 4b is the noise of TLS data, which, however, does not in any way affect the information content of the data on trunks and crown shapes.

**Figure 3.** The general outlook of constructed scene and RMS report. RO, R1, and R2 are georeference points.

**Figure 4.** A dense cloud of points provided by aerial survey (a) and the result of its joining with the data of terrestrial laser scanning (b).

**Figure 5.** Semi-automatic measurements of trunk diameters at given heights by means of Recap (a) and automatic measurements of trunk diameters and tree heights by means of 3D-forest software (b).
This technological scheme makes it possible to generate the cross-section of a dense cloud at a given height, which allowed us to measure the diameters and spatial allocation of trunks at any height with given intervals (figure 5a), first of all, at breast height (figure 5b).

4. Discussion
Hence, the technology allows one to calculate the coefficients of trunk form, the species-specific relative trunk volume, and taper value without logging a series of model trees. These parameters are demanded for the compilation of regional taper tables and the verification of mass methods of control of harvested timber.

In addition, shapes of trees obtained as dense clouds can be used to form the data banks for the computer-assisted classification, which allows to determine stand species composition automatically.

The three-dimension models of stand are requested in landscape design; they can be used in urban forestry to determine the existing and planned type of spatial structure and select trees for landscape improving cuts. Having a series of scenes constructed for a model plot with the interval of several years, it is possible to initiate the monitoring of stand spatial structure.

A detailed information on the form, size, and shape of tree crowns is of a great interest for the specialists in thematic proceeding of high-resolution hyperspectral data. These parameters affect the dispersion indicator of an object, which is the angular distribution of intensity of dispersed component of optical or electromagnetic radiation. It depends on the size, geometric form of disperser and relative index of refraction. This creates the possibility to form reliable sampling for tutorials and verification and better adjust the algorithms of computer-assisted processing of remote sensing data for forested areas.

In the nearest future, we plan to specify the planning of flight mission in order to get the most representative dense cloud of points, to study the perspectives of mobile terrestrial laser scanners (SLAM technology) for the construction of measuring forest scenes, and integrate the auxiliary information from orthophotoplans to computer-assisted processing of dense cloud of points for forested areas. Another promising field is the work with light regime evaluating both scenic beauty value and effect of light availability on tree growth.

The information content of multi-season aerial photography and generated dense clouds of points is to be analyzed for improving three-dimensional modeling of individual trees. Additionally, it is necessary to assess the prospects for the use of special flight missions, such as double grid and enhanced 3D from the standpoint of the quality of the data obtained and work productivity.

5. Conclusion
The combination of orthophotoplan obtained form an UAV and dense cloud of points from terrestrial lazed scanning helped us to eliminate the shortcomings of each of these methods and enhance their advantages.

The devices used in this study are the most accessible among multiple devices with analogical characteristics offered at the market. This device complex is the most money-saving for the suggested method and envisages minimal operator participation in the process of data collection and processing.

The scales of territories where the method can work depend on the rate of collection of field data and available computing facilities. Gaining and processing the information for 1 ha of forested land took one working day. However, the cameral stage proved to be power-demanding.

Therefore, the method relying upon the described devices is applicable for the studies of model locations and resolution of validation tasks.

The characteristics, which can be obtained reliably from a compiled three-dimension scene, are trunk diameters at different heights, tree height, trunk and crown form.

The described procedure is helpful for detailed measurements of dendrometric parameters without logging of model trees, obtain large representative samplings and use them for the compilation of regional taper tables. Three-dimension measuring scenes provide a realistic picture of forest landscapes, which is the base for designing the types of stand spatial structure.
References

[1] Rahman M T and Rashed T 2015 Urban tree damage estimation using airborne laser scanner data and geographic information systems: an example from 2007 Oklahoma ice storm. Urban. For. Urban. Gree. 14 562 doi: org/10.1016/j.ufug.2015.05.008

[2] Plowright A A, Coops N C, Eskelson B N I, Sheppard S R J and Aven N W 2016 Assessing urban tree condition using airborne light detection and ranging. Urban. For. Urban. Gree 19 140 doi: org/10.1016/j.ufug.2016.06.026

[3] Popescu S C, Wynne R H and Nelson R F 2003 Measuring individual tree crown diameter with LiDAR and assessing its influence on estimating forest volume and biomass. Can. J. Remote. Sensing. 29(5) 564 doi: org/10.5589/m 03-027

[4] Bienert A, Scheller S, Keane E, Mullooly G and Mohan F 2006 Application of terrestrial laser scanners for the determination of forest inventory parameters. Int. Arch.Photogramm 36(5) 1

[5] Trochta J, Krucek M, Vrska T and Kral K 2020 3D Forest: an application for descriptions of three-dimensional forest structures using terrestrial LiDAR. PLoS ONE 12(5) e0176871. doi: org/10.1371/journal.pone.0176871

[6] Starikov A V and Baturin K V 2015 Application of lazer scanning in timber accounting technologies. Forest Technical Journal 5(4) 114 doi: 10.12737/17409 [In Russian]

[7] Shnaidnman A, Oosterom P, Lemmen C, Ploeger H and Karki S 2019 Analysis of the third FIG 3D cadastres questionnaire: status in 2018 and expectations for 2022. Proc. of FIG Working Week Geospatial Information for a Smarter Life and Environmental Resilience (Hanoi: FIG) p10080

[8] Geographic Information – Land Administration Domain Model (LADM) International Organization for Standardization, available at: https://www.iso.org/obp/ui/#iso:std:51206:en

[9] Kalogianni E, Oosteom P, Dimopoulou E and Lemmen C 2020 3D land administration: a review and a future vision in the context of the spatial development lifecycle. ISPRS Int. J. Geo-Inf. 9(2) 107 doi: org/10.3390/ijgi9020107

[10] Forest Design Project, available at https://forestdesign.ro/index.php/ro/

[11] Coote A et al. 2017 Assessing the Economic Value of 3D Geo-Information (EuroSDR) p 127

[12] Mikhailov A P and Chibunichev A G 2016 Photogrammetry (Moscow: MSUGG Publishing) p 294 [In Russian]