Estimation of dendrometric characteristics in city parks according to data from UAVs and ground-based LiDAR

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Abstract. The possibilities of using ground-based LiDAR and processing of aerial photography data to assess the characteristics of individual trees in urban parks are shown. The actual data obtained during the examination of the object by these methods made it possible to analyze the state of the plantation and identify dendro parameters. It has been established that the methods of automatic search for trees using 3D point clouds can be successfully used in artificial plantations. The UAV data processing method made it possible to correctly detect in automatic mode about 64% of the park's trees (343 trees), while the number of false positives and the number of missed trees was quite high (111 and 195 trees, respectively), which was associated with a large proportion deciduous trees in the park. The weighted average of the quality of automatic tree detection in the park was 0.69. Ground-based LiDAR data in manual mode made it possible to detect all trees, determine their heights, crown diameter and trunk diameter at a height of 1.3 m, as well as identify tree species and condition category (using panoramic images). To increase the correctness of tree detection by 3D point clouds, the methods used need to be improved.

1 Introduction

Traditional inventory methods for urban forest stands [1] include a visual assessment of the state and measurements of the biometric parameters of trees. These data are actively used in the preparation of dendrological plans and inventory sheets in the urban economy. According to studies [2], the inventory of urban vegetation provides the ability to control the actual state and dynamics of green infrastructure at various spatial levels. In this case, the following parameters are taken into account:

- Area of the territory, natural and climatic conditions and microclimate.
- Species composition and dendrometric data (tree height, crown diameter and trunk diameter at a height of 1.3 m).
- The condition of the trees, including an assessment of exposure to various factors (burns, frost, pests and diseases).
- The value of plantations and the ecosystem services they provide (for example, carbon sequestration, microclimate regulation, etc.).

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The conclusions of [3] show that traditional park inventory methods are highly labor-intensive, time-consuming and have a certain degree of subjectivity. When solving similar problems (on the territory of natural forests), remote sensing systems were used to obtain data of high spatial resolution - aerial photography from unmanned aerial vehicles (UAVs) and laser scanning LiDAR (Light Detection and Ranging). These systems make it possible to obtain digital point clouds (point clouds) of objects of study, ready for comprehensive analysis. Already, these technologies are used to assess the characteristics of individual trees in the inventory and management of natural forests [4] and to assess the sanitary condition of forest stands [5]. The issue of using UAVs and LiDAR in solving the problems of inventorying city parks has not been sufficiently developed. The purpose of the study is to assess the possibility of using ground-based LiDAR and aerial photography from UAVs for the tasks of inventorying urban (artificial) plantings. In addition, the task was to evaluate the statistical relationships between the identified dendrological parameters (tree height, crown diameter, and trunk diameter at a height of 1.3 m).

2 Materials and methods

The material was collected in the Governor's Garden park in Petrozavodsk (Russia; Fig. 1). The park is located in the historical center of the city, it is a monument of landscape architecture and one of the oldest parks in Karelia. Initially, the territory was a farmstead of the residence of the Olonets governor and vice-governor at the end of the 18th century, after which the park bears its name [6]. Probably, the initial layout of the park was made in a landscape style, but later the park began to take on the features of a regular one. The relief of the park is gently sloping with a height difference of less than 5 m throughout the territory. The area of the park is 3.2 hectares.

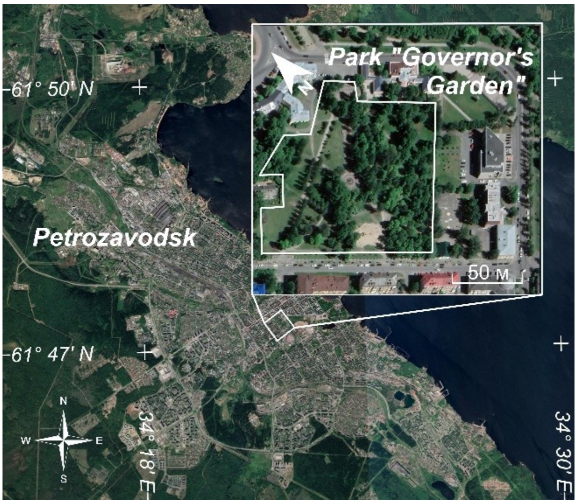

Fig. 1. Location of the Governor's Garden Park (Petrozavodsk, Russia).

A Leica BLK360 laser scanner (Switzerland) was used to conduct ground-based LiDAR surveys (Figure 2, left). This LiDAR has a low error (less than 6 mm for every 10 m survey) and a small laser spot size (2.25 mm) with a survey range of up to 60 m. The scanner allows you to receive only local (X, Y, Z) coordinates of the studied objects in metric geographic link. To capture the color of the point clouds, the scanner has a built-in RGB camera that takes a 360° panorama photo before each scan.

To carry out the survey, the scanner was preliminarily mounted on a tripod and centered. The route passed along the road and path network of the park (Figure 2, right). The distance between the stations was about 12 ± 2 m. The survey process was carried out without the use of marks in the high density mode for one day, the total number of stations was 52 pcs. During the shooting, the data was first stored in the scanner and transferred to the iPad 12 Pro tablet via WiFi. Also, in the field, preliminary stitching of data was carried out using the Cyclone FIELD program installed on the tablet. Further data registration was carried out in the Cyclone REGISTER 360 software. Dendroparameters were also measured manually there. Heights were measured to the highest point of the top of the tree.

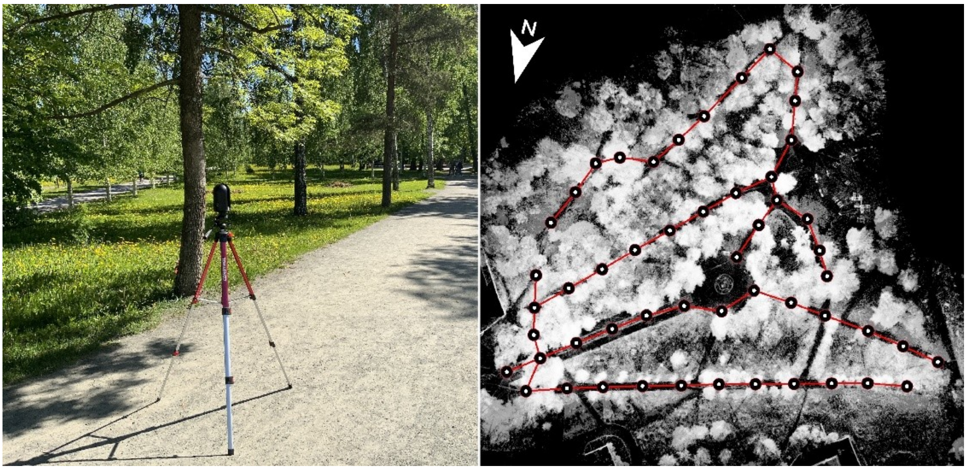

Fig. 2. The process of stationary LiDAR survey (on the left - the Leica BLK360 laser scanner at the station; on the right - the location of stations in the park (survey route).

For aerial photography, a DJI Phantom 4 pro quadcopter was used. This UAV is equipped with an inertial measurement unit (IMU) and GPS, which determine the position and height of the drone in space during flight, so that photos are obtained with known geographical coordinates of their centers. The RGB images obtained with this system are 5472 × 3648 pixels in size, the spatial resolution of the resulting composite image depends on the aircraft's flight altitude and image overlap.

The Pix4DCapture mobile application was used to construct the flight task. The flight took place in the Polygon mode with a flight altitude of 80 m, a camera tilt angle of 80°, and an image overlap of 70%. The configuration of the area to be filmed was set in the form of an octagon. Photogrammetric processing of images was carried out in the software Agisoft Metashape Professional Version 1.7.3.

The search for trees and the calculation of dendroparameters were performed using photogrammetric point clouds using the statistical programming environment R using the functions of the specialized package lidR v. 3.2.3. At the first stage, the procedure for classifying the set of points into 2 types was carried out: points of the earth's surface and other points located above. Ground surface points were identified using the cloth simulation filtering algorithm implemented in the lasground() function. Next, point clouds were normalized with respect to points on the earth's surface using the tin algorithm in the lasnormalize() function. At the final stage, a digital height model was built using the pitfree algorithm implemented in the grid_canopy() function. After that, using the tree_detection() function, we performed an automatic search for tree vertices in the point cloud. Then, using the obtained coordinates of the tree vertices, the crowns of the corresponding trees were segmented using the segment_trees() function.

For verification, the results of the automatic search for trees were compared with the orthophotomap of the area and field counts. For this, the number of trees (*TP*) correctly detected by the algorithm, the number of false positives (*FP*), and the number of missing trees (*FN*) were determined. The quality of the algorithm was evaluated using generally accepted methods [7], for this, the values of the detection completeness p, the detection quality r, and the weighted average quality score *F* were calculated.

3 Results

The results of the field survey showed that 25 species of woody plants grow in the park, of which 21 species are represented by trees, 4 species are shrubs. The total number of woody plants was 538 pcs. The dominant species are *Acer platanoides* L. 175 pcs. (32.5% of the total number of plants recorded), *Tilia cordata* Mill. 90 pcs. (16.7%) and *Betula pendula* Roth 86 pcs. (16.0%). Coniferous trees are few and only two species - *Larix sibirica* Ledeb. and *Pinus sylvestris* L.

In general, the state of trees and shrubs in the park is good: 386 pieces. or 71.7% of the total number of examined plants without signs of weakening. The number of weakened plants was 113, i.e. 21% of the total number of plants, severely weakened - 15 pcs. (2.8%), shrinking - 23 pcs. (4.3%), dead wood of the current year - 1 plant (0.2%).

The total registration of point clouds from 52 ground-based LiDAR stations gave an average standard deviation of 8 mm with a total number of points of 2.148 billion with an average density of 8.7 thousand points/m². The LiDAR point cloud made it possible to manually detect all the trees growing in the park and calculate their biometric parameters, while the BLK360 panoramic image made it possible to determine the plant species and the category of sanitary condition. As a result of measurements using the LiDAR point cloud, the average values of the trunk diameter at a height of 1.3 m, the average crown diameter and plant height were determined. The measurement results for the LiDAR cloud are presented in Table 1. 1 for the three most commonly found species in the park.

Table 1. Values of dendroparameters in the park (LiDAR).

View	Number of trees, pcs	Trunk diameter at a height of 1.3 m, cm	Crown diameter, m	Total height, m
Acer platanoides	175	24.4±3.1	6.8±0.8	14.3±1.1
Tilia cordata	95	32.2±2.2	7.7±1.2	15.7±1.8
Betula pendula	86	29.1±1.3	6.8±0.8	16.9±2.2

As a result of the UAV flight, 241 images were obtained. Photogrammetric processing of materials made it possible to obtain an RGB orthomosaic with a spatial resolution of 1.6 cm/pixel and a dense cloud of points of 45.4 million pieces. with an average density of 1.2 thousand dots/m². The reproduction error was 0.7 pixels with a size of 2.53 x 2.53 µm.

As a result of running the tree search algorithm using photogrammetric point clouds, 480 objects were found using the lidR package. Part of the detected objects (26 items) fell on structures (lanterns, poles, etc.). Ground counts in the park identified 538 trees, and automatic detection 454 trees, which, in total, is 84.4% of the total number of trees. At the same time, only a part of the trees were found correctly - 343 trees (63.7% of the total number of trees). The number of false positives and the number of missing trees were quite high (111 and 195 trees, respectively). The weighted average quality score for the entire fleet was 0.69.

For all correctly detected trees, the heights obtained as a result of automatic calculations were compared with the heights measured manually using the LiDAR cloud. When comparing the heights, it turned out that the heights estimated by the algorithm from the

UAV data were in good agreement with the data measured from the LiDAR clouds (Figure 3). The convergence of estimates between the heights of the same trees obtained by different methods is very significant (R^2 = 0.97), and no significant differences were found.

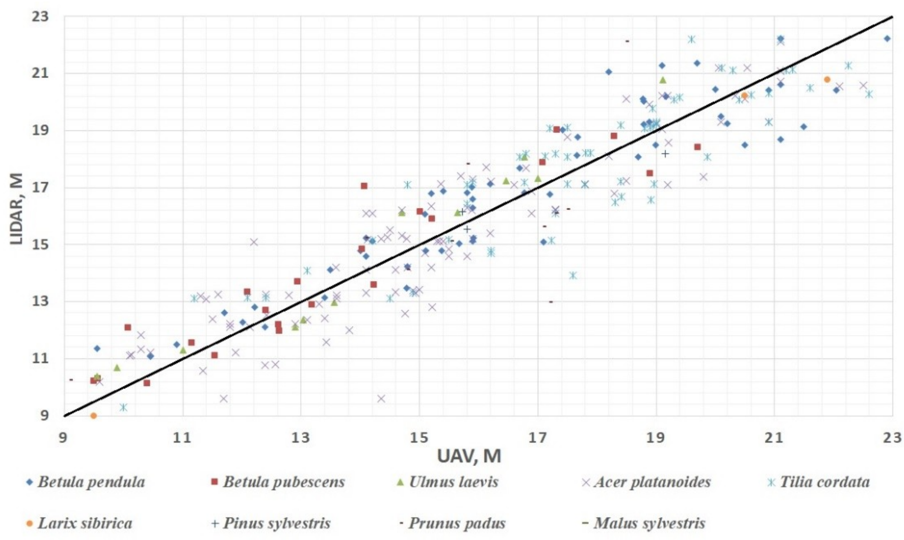

Fig. 3. Comparison of tree heights obtained from UAV and LiDAR data.

The calculation results made it possible to construct regression equations for the relationship between individual dendrometric parameters. Their importance is due to the fact that the identified dependencies allow, based on the values of one dendroparameter, to establish the values of others. Table 3 presents the parameters of the equation for the dependence of the diameter of the trunk at a height of 1.3 m ($d_{1.3}$, cm) on the height of the tree (h, m) and crown diameter (D_k, m).

The value of the multiple coefficient of determination (R^2) for the characteristics of *Acer platanoides* was 0.63, for the characteristics of Tilia cordata, 0.75. In *Betula pendula*, the dependence between the diameter at a height of 1.3 m and the crown height and diameter turned out to be weaker, 0.44.

Table 2. Parameters of the regression equation $d_{1.3} = a{\cdot}D_k + b{\cdot}h + c$, describing the relationship between the trunk diameter at a height of 1.3 m ($d_{1.3}$, cm) and the crown diameter (D_k, m) and height (h, m).

View	The value of the coefficient *a*	The value of the coefficient *b*	The value of the coefficient *c*	R^2
Acer platanoides	2.52	131	–11.39	0.63
Tilia cordata	2.56	1.11	–3.81	0.75
Betula pendula	1.86	1.20	–3.88	0.44

4 Discussion

The use of UAVs in the inventory of the park made it possible to obtain a geo-referenced orthophotomap with a high spatial resolution and a visible projection of the crowns of individual trees, however, an accurate (centimetric) alignment of trees (their butts) according to these data is practically impossible. For tree-by-tree topographic survey of artificial plantations, it is more expedient to use LiDAR ground-based laser scanning, combined with the results of photogrammetric processing of aerial photography data or field surveys.

From the latest published literature data, it is known that automatic recognition of tree species based on aerial photography and LiDAR is currently used only on a small number of tree species (up to 5-8) and in natural forests. In [8], the authors managed to train a neural network and automatically identify five types of trees with an accuracy of more than 85%. In [9], there are seven types of trees with an accuracy of about 80%. The results of these studies indicate the impossibility of their application in areas with a high diversity of trees (city parks, arboretums), therefore, in the framework of the study, the species affiliation of trees was determined only on the basis of panoramic images and field surveys.

At the same time, the results of the automatic search for individual trees (in pieces) using 3D point clouds show that the selected tree detection algorithm showed ambiguous results in practice (only 63.7% of the trees in the park were found correctly), which indicates a partial possibility of their application in artificial stands and insufficient development of the selected algorithms. It is likely that such high values of the number of false positives and missing trees are associated with the high crown density of deciduous trees in the park (the total share of deciduous trees is 91%), since with a high projective cover of tree crowns, tree tops are not identified, and their butts and roots are not visible. the earth's surface, which generally makes it difficult to identify and extract the desired tree parameters. These results confirm the already published data obtained by scientists at other sites (natural) [10].

The results of comparisons of tree heights obtained by different methods indicate the possibility of using these methods in the study of dendro parameters in artificial plantations. The use of ground-based LiDAR, in contrast to UAV data, makes it possible to correctly extract the characteristics of a tree trunk and crown. Due to the built-in digital camera in the selected LiDAR (Leica BLK360), according to the received data, it is possible to manually identify the species and categories of tree condition, which allows replacing routine work in the park with cameral processing.

The results of the regression analysis of the calculation of the relationship between individual dendrometric parameters showed that the models obtained for the characteristics of *A. platanoides* and *T. cordata* are acceptable. The practical application of the equation for the characteristics of *B. pendula* is of low value. These results allow us to conclude that part of the field measurements for *A. platanoides* and *T. cordata* can be replaced by calculated values.

5 Conclusion

Using the example of the Governor's Garden park in Petrozavodsk, the applicability of ground-based LiDAR and aerial photography data processing to assess the characteristics of individual trees is shown. The actual data obtained during the survey of the object made it possible to analyze the state of the plantation. It has been established that such methods can be successfully used to assess the biometric characteristics of individual trees. The UAV data processing method, despite the high proportion of deciduous trees in the park, made it possible to correctly detect about 63.7% of the park's trees in automatic mode. Ground-based LiDAR data in manual mode makes it possible to detect all trees, determine their heights and crown and trunk diameters, as well as identify tree species and condition category. To increase the correctness of tree detection by photogrammetric point clouds, the methods used need to be improved.

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