GLL
Geomatics, Landmanagement and Landscape No. 1 • 2025, 245–260

ISSN 2300-1496 https://doi.org/10.15576/GLL/202431

Research paper

Received: 17.01.2025
Accepted: 13.02.2025
Published: 31.03.2025

Studies in the stereometry of large growing trees by terrestrial photogrammetric method

Nazar Tretyak[1] 0009-0003-4774-5835
Platon Tretyak[2, ✉] 0000-0001-8278-060X

[1] Department of Geoecology and Land Management, Dmytro Motornyi Tavria State Agrotechnological University, Zaporizhia, Ukraine
[2] Department of Regional Biocenotical Monitoring, State Natural History Museum of the National Academy of Sciences of Ukraine, Lviv, Ukraine
✉ Corresponding author: platon.tretyak@gmail.com

Summary

The study has developed a geometrical toolset to calculate biometric parameters of large growing trees using distorted images captured by a digital camera. This toolset focuses on determining a variable scaling factor that accounts for the camera's inclined position relative to the horizon. An algorithm for the software and an associated online web service has been created. For measurements, a standard ruler, such as one that is 1,000 mm long, is placed on the tree trunk at a height of 1.3 m from the base. The distance from the lens to the standard is measured with an accuracy of ±0.2%. The trunk thickness (DBH) measurement accuracy is not below 1 mm per 1 pixel. This analysis derives from the similarity of triangles in the camera's field of view, specifically from the lens to the tree trunk and from the lens to the image sensor. The parameters of the digital image are essential, particularly the lens's focal length varying from 20 mm to 200 mm. Similar but more complex geometric proportions are applied, in case the trunk is vertical. The process involves considering the tilt of the camera matrix to the horizon, and the slope from the lens to the standard reference point. Key factors include the predetermined distance and slope from the lens to the standard on the trunk, along with the parameters of the digital image, particularly the lens's focal length, typically ranging from 6 to 10 mm. An online web service is offered to perform the relevant measurements and calculations. The software facilitates automatic calculations and generates a data array containing scaling factors corresponding to various height levels from the tree base. Simultaneously, a Visual Basic command array is produced to mark the digital image of the tree at these height levels, complete with scaling factor indicators. This method enables the measurement of trunk thickness at the required heights in pixels, which can then be converted into millimeters. The measurement accuracy is from 6 to 10 millimeters per pixel. The collected data is subsequently organized into a table in Excel. Then, the cross-sectional areas of all trunk segments and their respective volumes were calculated. The total trunk volume is determined by summing the volumes of these segments. The proposed methodology is original, has no prototypes, and may be suitable for practical application.

Keywords

terrestrial photogrammetry • digital camera • image distortion • web service • online tools • scaling factors

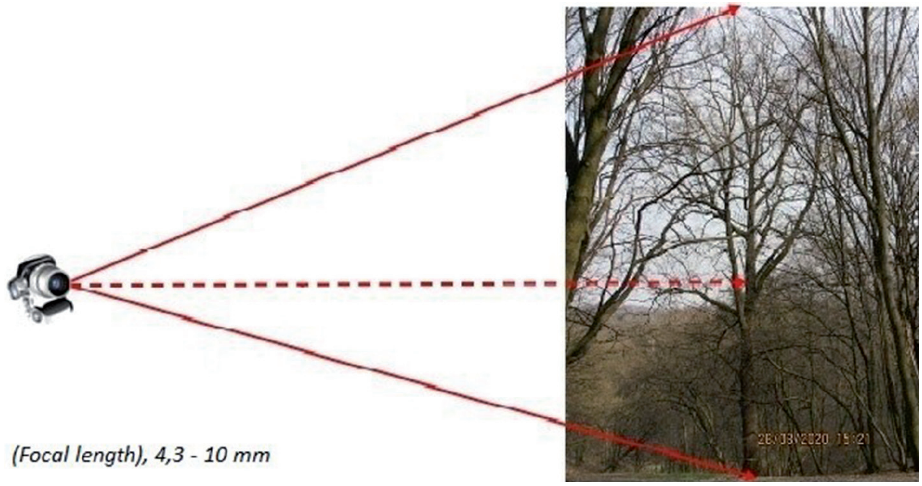
1. Introduction

There are very few large ancient trees left in nature. In different countries of the world, such monumental trees are standards of tree growth that are protected. However, existing web services provide mostly data on the height of such trees, their thickness, and their perimeter at a height of 1.3 m from the ground surface [Monumental Trees 2022]. Unfortunately, there is no data on their trunk wood volume and its increase. These indicators determine the vitality and ecological functions of trees. In particular, this applies to their material and energy impact on the environment [Chernevyy et al. 2024]. Currently, there are no methods for calculating these parameters of giant growing trees. There are various methods of defining the parameters of felled trees, including Huber's formula, Smalian's formula, and others [Prodan 1968, Tsuryk 2006]. Technically, it is challenging to apply such methods to the giant trees that are growing since they require measuring the trunk thickness at different heights. Ground-based instrumental stereometric measurement, as well as photogrammetry and 3D scanning, could be promising methods. However, there are problems with visual measurement of different tree segments caused by their various shapes, branches of the crown, and foliage. Attempts at ground-based laser scanning do not give complete measurements of all structural parts of the tree [Wu et al. 2011]. The same applies to 3D scanning using drones [Chenbing 2023].

Aerial photography and photogrammetry methods using large-scale images have also gained popularity [Sayn-Wittgenstein 1967, Phattaralerphong et al. 2005]. Recently, there have been attempts at approximate photogrammetry of tree trunks from different sides using smartphones. GPS equipment was additionally used to refine positioning [Marzulli 2019]. Special measuring and raster boards 2 m high and 1.2 m wide were also used to increase the accuracy of measurements of trunk parameters. This allowed for accurate determination of the thicknesses and volumes of various sections in the lower part of the trunk. For the heights above 2 m, calculations were conducted using the cone formula, which allowed for a more accurate determination of tree height. This approach yielded results that differed significantly from those obtained through traditional methods [Coelho et al. 2021]. However, a major challenge with this method was its reliance on a constant scaling factor k, defined as the ratio quantity of metric units in nature to the corresponding quantity of pixels in the image. Since a digital image of a tree trunk contains areas at various distances from the camera lens, this scaling factor should be variable, increasing from the level of the horizon to the top of the tree. Unfortunately, this issue was not addressed in the presented method.

The initial conditions for solving this problem are as follows:

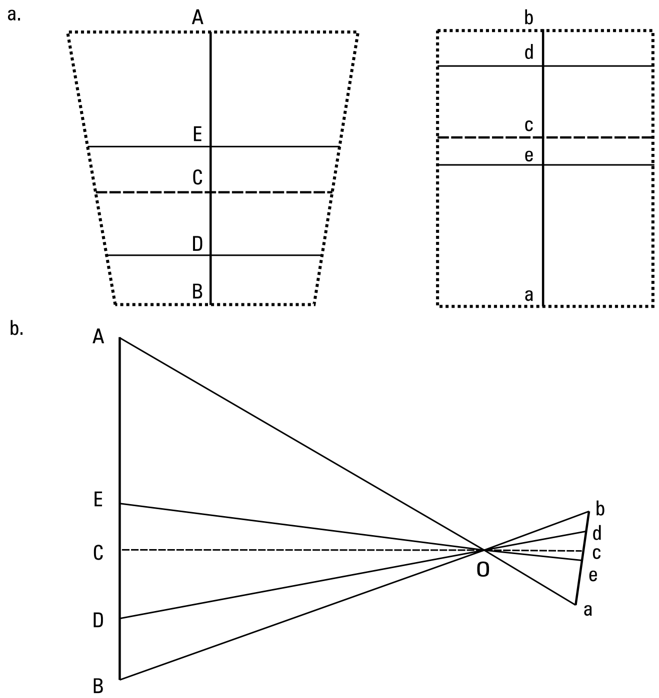
1. The tree grows vertically and can attain a height of 30 to 40 m or more.
2. The digital camera is positioned at the level of the tree trunk base or higher, at a distance that exceeds the tree's height (Fig. 1).
3. The camera's field of view encompasses an inverse trapezoidal plane within the tree trunk so that its matrix is angled at a certain inclination relative to the horizon (Fig. 2).
4. The rectangular image captured on the matrix will be distorted to represent accurately the real shooting plane. Consequently, the scaling factor of the resulting image will tend to increase quantitatively from the base of the tree to its top.



Source: Authors' own study

Fig. 1. Diagram of a growing tree photographed with a digital camera

Under these conditions, the method of ground photogrammetry for large, growing trees must consider how the measurement coefficient depends on both the inclination angle of the camera sensor and the visualization angle from the lens to the tree base. Therefore, our **objective** was to create a novel method of ground photogrammetry for large trees using a digital camera, specifically tailored to these conditions. This involved developing the necessary geometric and mathematical frameworks, as well as software support for calculations. Additionally, we aimed to create a service-oriented software system and an analytical online platform. This development is unprecedented and has no analogs in the scientific literature or online resources.



Source: Authors' own study

Fig. 2. a. Real trapezoidal plane of the camera field of view and its rectangular image on the matrix. b. Diagram of stereometric distortion of the physical image on the camera matrix

2. Methods and materials

The study of tree biometrics involves determining the spatial parameters of the trunk and its large branches. These include the basic spatial characteristics of a growing tree: its height (*H*), trunk thickness at a height of 1.3 m (DBH) from its base, its volume (*V*), and form factor (*f*). The latter refers to the fraction of the trunk volume compared to the volume of a cylinder. The cylinder's height is equal to the tree's height, and its base area is equivalent to the cross-sectional area of the tree at a height of 1.3 meters. The spatial characteristics of the branches include their length, thickness, and volume. Their stereometric features can be viewed, with some assumptions, as a certain generatrix of rotational figures. In terms of shape, the lower part of the trunk resembles a neyloid, the middle section approximates a truncated paraboloid, and some short segments can be likened to either a cylinder or a truncated cone. Lastly, the top section resembles a cone. This observation also applies to the larger branches [Prodan 1968, Tsurik 2006]. The most common method of determining the trunk volume is to divide it into separate sections of 2 m length. However, their length can be 1 m or 0.5 m in the basal part. The following formula determines the volume of each part:

$$V = l \cdot \frac{(g_1 + g_2)}{2} \tag{1}$$

where:
l – the length of the trunk segment,
g_1 and g_2 – cross-sectional areas in the lower and upper parts of the trunk segment.

Determining the cross-sectional areas is based on the average thickness of the tree. For a lying tree, this is a straightforward procedure, but for a growing tree, it presents a significant challenge. Measurements can be conducted using laser 3D scanning. This method, however, has limitations regarding the upper-branched sections of the tree trunk and crown.

Our approach utilizes terrestrial photogrammetry to capture a detailed image of the growing tree trunk with a high-resolution digital camera. Most digital cameras used in this method had a resolution of 16 megapixels, with dimensions of 3456 × 4608 pixels, or approximately 4.55 × 6.17 mm. This means that when photographing a 40 m tall tree, we can obtain an average vertical accuracy of about 0.87 cm per pixel. Given a tree's thickness of 2 m, such resolution can be reached at 0.4 mm. When using modern cameras with a resolution of 32 megapixels or more, the average accuracy of the captured images can be two to three times higher. However, a significant challenge arises in calculating the thickness of trunk elements based on their vertical positioning. When the shooting point is situated close to the base of the tree, the rectangular image captured by the camera sensor shows a trapezoidal area within the trunk's field of view (Fig. 2a). As a result, the distortion of the image dimensions is related not only to the distance from the lens to the tree but also to the angle at which the camera matrix is inclined (Fig. 2b).

Under these conditions, the conceptual principles for calculating the parameters of a growing tree will rely on the ratios between the spatial characteristics of the real image volume and the corresponding image captured by the digital camera's sensor. Consequently, the primary initial data will be the parameters of the camera matrix, specifically the total resolution and its geometric dimensions, which include width and height measured in both pixels and millimeters. So, using a matrix with a volume of 16 megapixels, the size of its larger side is 6.17 mm (variable $h_m), or 4608 px (variable $h_f)[1]. Thus, the size of one pixel on the larger side of the matrix is 0.0013389757 mm (variable *m*1). Accordingly, the size of the smaller side is 4.55 mm (variable $w_m), or 3456 px (variable $w_f). In this case, the size of one pixel on the smaller side of the matrix is 0.0013165509 mm (variable *m*2). The values of these variables are used to calculate the exact stereometric parameters of a digital camera. Another determining

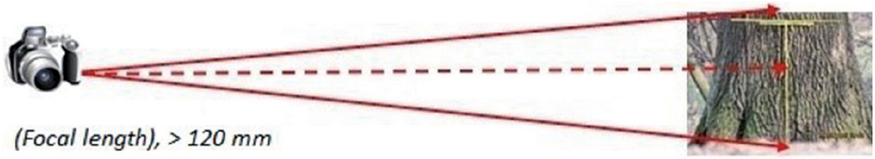
[1] Since the purpose of the presented work was to create an original computer program for use on the Internet, this article uses the concept of a variable. Each such variable in programming languages has a standard identifier; in our case, we used the php programming language, so variables are denoted by the '$' sign. Accordingly, the article indicates what initial and intermediate data are assigned to specific variables. This is necessary in order to distinguish them from the executable text, and especially in the program flowchart.

factor is the camera's lens focal length, ranging from 5 to 200 mm (variable $focal_ lenght). Its value for a specific digital image can be obtained using the exif data viewer of the photo, preferably with two decimal places.

To make geometric comparisons between nature and the image on the matrix, we use a horizontal standard represented by a ruler 1,000 mm long (variable $etalon). An image of this standard on the matrix corresponds to a certain number of pixels (variable $etalon_pks). This can be expressed in linear measurements, in millimeters, by taking into account the values of the variables *m*1 and *m*2.

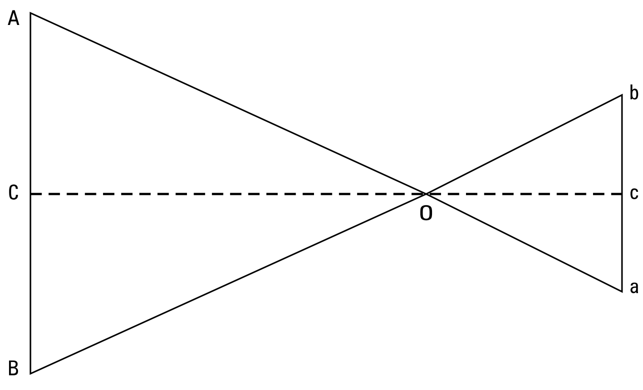
First of all, we establish the distance from the camera lens to the standard on the tree trunk (variable $dist), as well as the tree thickness at the height of the standard (variable $thick_mm). We install the digital camera horizontally at a height of 1.3 meters. Using a translocator, we focus the camera's angle of view on the lower part of the tree trunk, ensuring that we capture the entire trunk thickness. A standard ruler is positioned in the center of the image for reference (Fig. 3).

We use the proportions of similar triangles shown in (Fig. 4) for the calculations.



Source: Authors' own study

Fig. 3. Scheme of digital camera photography of the tree base to determine the distance to the standard and the trunk thickness (DBH)



Source: Authors' own study

Fig. 4. Calculation of the distance from the standard to the lens (variable $dist) and the tree trunk thickness (variable $thick_mm), where: *AB* – the length of the standard in millimeters (variable $etalon), *O* – the location of the camera lens, *Oc* – the distance from the lens to the camera matrix, *ab* – the length of the standard image on the matrix in millimeters (variable $etalon_pks)

Provided, the digital camera is positioned horizontally, we use the variable $\$m1$ as a multiplier to convert the image size of the standard *ab* from pixels to millimeters. Initially, we determine the approximate distance from the standard to the camera lens:

$$OC = \frac{AB}{ab \cdot F} \tag{2}$$

where: *F* – the lens' focal length (variable $focal_lenght).

The following formula determines the distance from the lens to the camera sensor:

$$Oc = \frac{AB \cdot F}{AB - F} \tag{3}$$

The specified value of the *OC* distance (variable $dist) is as follows:

$$OC = \frac{AB}{ab \cdot Oc} \tag{4}$$

Using this method, the measurement accuracy is +0.2% at a distance of *OC* = 50 m and *F* = 100 mm, i.e. the refined *OC* distance is 50.1 m. Similarly, we measure the thickness of a tree at a standard height of 1.3 m. Having obtained the thickness of the trunk, we add half of it to the preset distance from the camera lens to the standard. Carrying out repeated calculations, we get a refined result of the thickness of the trunk. For example, if the trunk thickness at the standard level is 2,000 mm, and its image on the camera matrix has a size of 3,000 px, then the measurement accuracy is 2/3 mm per 1 pixel. So, we can assume that it is no worse than 1 mm per 1 pixel.

Similarly, we perform a digital survey of the trunk of a growing tree by placing the camera in a vertical position (Fig. 1). We calculate the parameters of the tree trunk by accounting for the stereometric distortion. It is caused by the inverse trapezoidal shape of the camera's field of view at the trunk's location under the rectangular image on the sensor. As a result, the scaling of the metric indicators (*k*) of the image on the sensor is uneven. It gradually increases from the base to the top of the tree. It is quantitatively represented as follows:

$$k = \frac{AO}{Oa};\ \frac{CO}{Oc};\ \frac{DO}{Od};\ \frac{BO}{Ob} \tag{5}$$

To accurately measure and calculate the parameters of a vertically growing tree trunk, it is essential to determine the scaling ratio coefficients (referred to as variable *k*) at various locations within the measurement matrix. This process utilizes principles of geometric construction, as illustrated in Figure 2b. The initial data required for these calculations includes the distance from the lens to the standard at a height of 1.3 meters on the tree trunk ($distance2). This distance was previously calculated as ($dist), along with the slope angle in degrees from the lens to the standard on the tree trunk $\angle COD$ (variable $slop). This allows us to calculate the horizontal distance from the lens to the tree trunk (variable $CO):

$$\$CO = \cos(\$\text{slop}) \cdot \$\text{distance2} \tag{6}$$

Accordingly, the distance from the horizon level to the level of the standard location on the tree trunk (variable $\$CD$) will be:

$$\$CD = \sin(\$\text{slop}) \cdot \$\text{distance2} \tag{7}$$

Traditionally, the trunk is divided into two parts: from the ground level to the tree base ($h1$) and from the ground to the top of the tree ($h2$). In the first case:

$$h1 = \$CD + 1.3 \text{ m} \tag{8}$$

In the second case: $h2 = AC$:

$$AC = CO \cdot \sin\angle AOC \tag{9}$$

$\angle AOC$ can be calculated from the proportions of the corresponding angles in the stereometric space of the digital camera (Fig. 2b).

To calculate the parameters of a growing tree based on its projection on a digital camera's sensor, it is essential to first determine the distance Oe from the center of the lens to the sensor. This can be done using formulas (2–4). We need to specify the focal length of the digital image in millimeters with an accuracy of two decimal places (\$focal_lenght2). Knowing the distance from the center of the lens to the matrix Oe, we calculate the parameters of the stereometric space of the digital camera:

$$Ob = \sqrt{Oe^2 + \left(\frac{ab}{2}\right)^2} \tag{10}$$

$$\angle bOe = \arccos(be/bO) \tag{11}$$

$$\angle bOe = \angle aOe \text{ (variable \$}\alpha\text{)} \tag{12}$$

Therefore:

$$\angle AOE = \angle EOB \text{ (variable \$}\alpha\text{)} \tag{13}$$

The distance DB from the reference point on the tree trunk to the lower edge of the camera's field of view is represented by the segment bd on the tilted matrix. The size of this segment, measured in pixels (variable \$d_pks), is converted to millimeters using the coefficient $m1$. This conversion allows us to calculate the length of the segment de, as well as its corresponding value $\angle dOe$:

$$de = \frac{ab}{2} - bd \tag{14}$$

$$\angle dOe = \text{arctg}(de/eO) \tag{15}$$

$$\angle bOd = \angle bOe - \angle dOe \tag{16}$$

$$\angle bOd = \angle BOD \text{ (variable \$}\beta\text{)} \tag{17}$$

$$\angle cOe = \angle bOe - \angle bOd - \angle cOd \tag{18}$$

$$\angle cOd = \angle COD \text{ (variable \$slop)} \tag{19}$$

Therefore:

$$\angle EOC = \angle eOc \text{ (variable \$}\gamma\text{)} \tag{20}$$

Thus:

$$\$\alpha = \$\beta + \$\gamma + \$slop \tag{21}$$

The inclination of the digital camera matrix relative to the horizon is (variable $slop2):

$$\angle Ocb = \angle COE + 90° \tag{22}$$

The scaling factor values of the image dimensions *k* (variable $k) depend on the mentioned proportions. Therefore, at the level of the standard on the tree trunk, points *D* are the following:

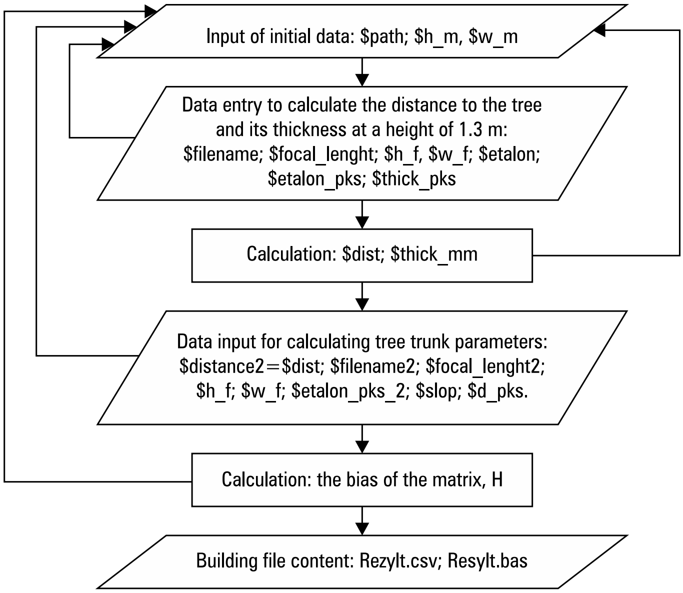
$$k = \frac{DO}{Od} \text{ or } k = \frac{\sqrt{\left(CD^2 + CO^2\right)}}{\sqrt{\left(Oe^2 + ed^2\right)}} \tag{23}$$

This ratio is best expressed in millimeters of distance *DO* to distance *Od* in pixels. The point *D* can be placed at any height of the tree trunk from its base, for example: 0.1 m; 0.5 m; 1.0 m; 2.0 m, and higher with an interval of two meters. According to each elevation mark, the coefficient value *k* (variable $*k*) can be calculated using the formula (23).

The algorithm calculates the ratio of the actual inverse trapezoidal plane of the camera's field of view to its representation on an inclined rectangular matrix. This algorithm is the foundation for the actions outlined in the flowchart (Fig. 5). For its implementation, we developed a custom computer program in PHP, along with a dedicated web form for service management using HTML (Fig. 6) [Tretyak and Tretyak 2020]. A step-by-step detailed 'User Instructions' was developed for its application.

In the upper section of this form, we input the dimensions of the digital camera matrix in millimeters. This includes the longer side (variable h_m) and the shorter side (variable w_m). Additionally, we provide the path to the user directory where the corresponding digital images of the tree trunk are stored (variable $path).

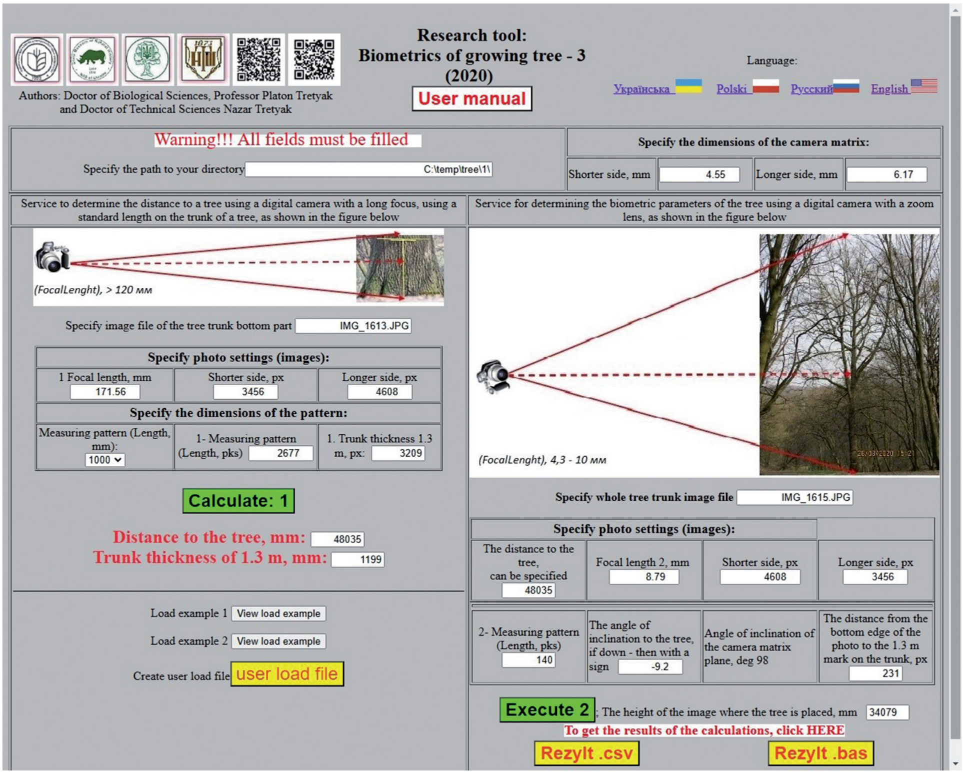
In the left window of the form, we enter the parameters for the image of the trunk base at the height of the reference in the appropriate fields. These parameters include the name of the digital image file (variable `$filename`), the image dimensions in pixels, including its longer side (variable `$h_f`) and its shorter side (variable `$w_f`), as well as the camera's lens focal length in millimeters (variable `$focal_length`). We also provide data on the standard size in millimeters (variable `$etalon`), the size of the standard image on the sensor in pixels (variable `$etalon_pks`), and the trunk thickness at the standard height in pixels (variable `$thick_pks`). By activating the option 'Calculate: 1', the data entered in the form fields are automatically assigned to their corresponding variables. This action then triggers the calculation of indicators based on the provided formulas (2, 3, 4). Next, the form is reloaded with the displayed calculation results. We determine the measurements needed: the distance from the lens to the standard on the tree trunk in millimeters (variable $dist) and the trunk thickness at the height of the standard, also in millimeters (variable $thick_mm). The obtained values of the corresponding variables are transferred to the initial data (Fig. 5).



Source: Authors' own study

Fig. 5. Flow chart of the software algorithm. Explanation of abbreviations follows in the text

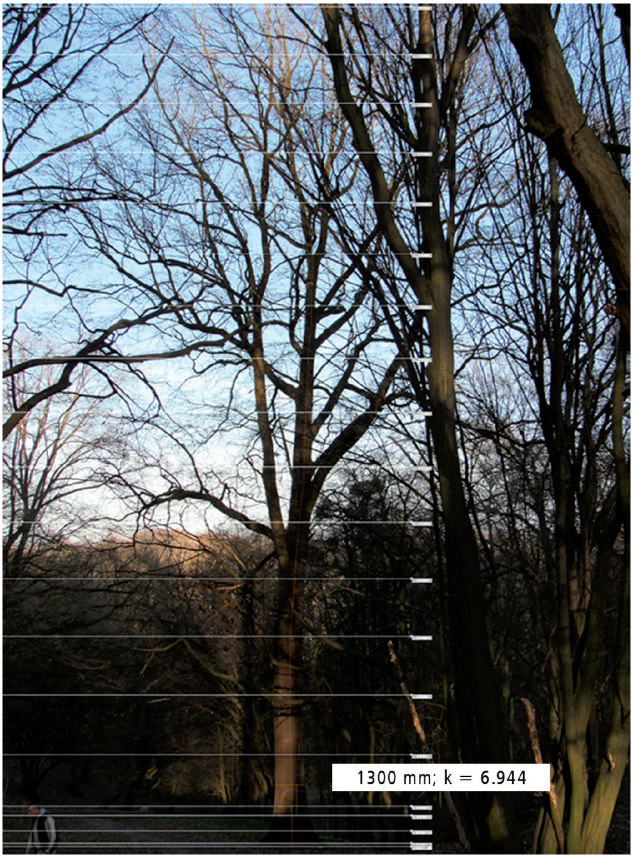
In the right window, we need to enter the following information: 1. The file name of the tree trunk image (variable $filename2). 2. The distance from the camera lens to the standard on the tree trunk (variable $dist2) automatically assigned based on the variable $dist. 3. The focal length of the digital image, measured in millimeters with an accuracy of two decimal places (variable $focal_length2). 4. The image dimensions in pixels: the longer side (the variable $h_f) and the shorter side (variable $w_f). 5. The length of the standard image on the sensor in pixels (stored in the variable $etalon_pks_2). 6. The distance from the bottom edge of the digital image to the standard on the tree trunk (variable $d_pks). After entering this information, we can activate the 'Execute 2' option. This action will transmit the specified variables to the server, where the program calculates the ratios of the trapezoidal dimensions of the camera's field of view to the corresponding parameters in the digital image. The inclination angle of the camera matrix relative to the horizon (variable $slop) will be determined, along with the coefficient values *k*, which are based on established gradations of the trunk height. These calculations are performed using the formulas (5–23). As a result, we obtain the plane height where the tree trunk is located in the trapezoidal image space, measured in millimeters. Additionally, two new buttons labeled ‘Rezylt.csv’ and ‘Rezylt.bas’ are created. When the ‘Rezylt.csv’ button is activated, a separate window appears, displaying the results of the calculations for the coefficient *k*, depending on the distance from the tree base (point *D*, as Fig. 2b). The results are presented as a text array, which includes consecutive records starting from the upper edge of the image on the matrix and moving towards the tree base. Each line represents the value of the coefficient *k* related to the height of point *D* on the trunk, measured in millimeters from the base of the tree (denoted as *H*), as well as in meters (*H*, m), and corresponds to its location on the digital image in pixels (*H*, p). This array is the foundation for creating a corresponding spreadsheet in Excel or similar applications. For this purpose, we first copy and paste the resulting data array into a text file with a *.csv extension. Then, we open the file in Excel and organize the data into separate columns, using the appropriate separators (;).



Source: Authors’ own study

Fig. 6. General view of the control web form of the service program ‘Biometrics of a growing tree’ – 3» http://econtsh.astra.in.ua/tree/tr_bm1.php?lang=en

By activating the 'Result.bas' button in a separate window, we obtain a text array that contains a command set for the Visual Basic programming language. Using the Microsoft Publisher environment, we create a digital image with markup for elevation levels. This image has a resolution of 3405 × 4591 pixels, which is converted to a size of 93 × 122 cm. This high resolution allows for precise cursor positioning and accurate measurement of trunk thickness. Figure 7 displays a reduced version of this image.



Source: Authors' own study

Fig. 7. Image of the plane of the tree trunk survey with the height levels marking. The callout shows the height of the level and the parameter *k*. Such indicators are given at all levels of the horizon

The trunk thickness measurements, recorded in pixels, are entered into the Excel table in column (*D*, p) corresponding to the appropriate elevation levels (Table 1). To determine the trunk thicknesses in centimeters, we multiply the given values by the current value of the coefficient *k* and record these results in the corresponding column (*D*, cm). Next, for each trunk thickness, we calculate the area of the circle in square meters and enter the results in column G (m²). This process allows us to create a data array for calculating the volumes of individual tree trunk segments (V, m³), which we compute using the appropriate formula (1). As a result, we obtain the value of the total volume of the tree trunk (V_t) and the corresponding form factor (f):

$$f = \frac{V_t}{g_{1.3} \cdot H} \tag{24}$$

where: $g_{1.3}$ – a cross-sectional trunk area at a height of 1.3 m from the base.

Similarly, we can calculate the volumes of large branches of the tree crown. In this case, their volume is added to the trunk volume.

The method described is suitable for trees whose trunks have a cross-section close to a circular shape. However, for trunks with an oval cross-section, it is recommended to measure the perimeter at a height of 1.3 m and calculate the average diameter of the equivalent circle. Based on this value, it is necessary to adjust the thickness measurements obtained from the digital image. Additionally, similar measurement procedures can be conducted using photogrammetry from the opposite side, preferably at a perpendicular angle to the previous view. This approach will help us to create two Excel tables, average the trunk thickness data, and perform the necessary calculations.

3. Results

The ground-based photogrammetry of the Common Oak, located in Zalizny Vody Park in Lviv, was conducted on March 27, 2024. The distance from the digital camera to the standard on the tree trunk was 40.90 m, with a slope of –9.2°. A vertical image of the entire tree trunk was captured using a Canon PowerShot SX530 HS digital camera with a lens focal length of 7.673 mm. The camera's matrix has a resolution of 16 megapixels, 4.55 mm high (3456 pixels) and 6.17 mm wide (4608 pixels). The results of the calculations are presented in Table 1. The trunk's thickness at a height of 1.3 m was measured at 129.2 cm, and its height reached 32 m. Our calculations indicated that the trunk volume is 15.995 m³, and the form factor is 0.370.

Table 1. Results of the biometric calculations for the trunk of a growing Common Oak tree as of March 27, 2024

H, m	*k*	*D*, p	*D*, cm	G, m²	*V*, m³
33		0	0	0.0000	
31	7.886	10	7.9	0.0049	0.0049
29	7.823	20	15.6	0.0191	0.0240
27	7.759	23	17.8	0.0249	0.0440
25	7.696	25	19.2	0.0290	0.0538

Table 1. cont.

H, m	*k*	*D*, p	*D*, cm	*G*, m^2	*V*, m^3
23	7.632	30	22.9	0.0412	0.0701
21	7.569	67	50.7	0.2019	0.2431
19	7.506	65	48.8	0.1870	0.3889
17	7.442	73	54.3	0.2316	0.4186
15	7.379	87	64.2	0.3237	0.5553
13	7.315	110	80.5	0.5090	0.8327
11	7.252	124	89.9	0.6348	1.1437
9	7.189	140	100.6	0.7949	1.4296
7	7.125	156	111.2	0.9712	1.7660
5	7.062	156	110.2	0.9538	1.9250
3	6.998	151	105.7	0.8775	1.8313
1.3	6.944	186	129.2	1.3110	1.8602
1	6.935	204	141.5	1.5725	0.4325
0.5	6.919	248	171.6	2.3127	0.9713
0.1	6.906	360	248.6	4.8539	1.4333
0	6.903	416	287.2	6.4783	0.5666
				Total	15.9951
				f	0.370

Notes: *H*, m – the height of the trunk section from the base to the cross-section measurement mark in meters; *k* – the scaling factor values of the image dimensions; *D*, p – thickness of tree trunk in pixels; *D*, cm – thickness of tree trunk in centimeters; *G*, m^2 – cross-sectional area of the trunk in square meters; *V*, m^3 – the volume of the trunk section in cubic meters

4. Discussion

The results obtained indicate a high accuracy level in measuring the tree trunk thickness, particularly at a height of 1.3 meters. In the first scenario, when measuring the distance from the camera to the standard point on the tree trunk, the calculated accuracy is 129.2/2427 = 0.053 cm per pixel. In the second scenario, where a full vertical image of the tree trunk is captured, the accuracy for measuring the trunk thickness at the standard height is 129.2/186 = 0.694 cm per pixel. This is based on a standard length of 1,000 mm, corresponding to 144 pixels on the camera's sensor.

Overall, the proposed method can provide sufficiently accurate measurements for monitoring changes in the tree thickness over time. However, determining the tree height with the same level of accuracy poses challenges due to the open structure of its crown, which complicates visualization. It is noteworthy that most of the trunk volume is concentrated within the first 23 meters, with only 0.127 m^3, or 0.79%, of the trunk volume located above this height (Table 1). This method is considered adequate as it calculates tree volume with an accuracy of up to 1%.

However, 3D laser scanning can be utilized for a more precise measurement of the lower trunk volume up to the tree crown. This technique will help us evaluate the accuracy of the proposed terrestrial photogrammetric method.

The recorded form factor values of 0.344 in 2020 and 0.370 in 2024 indicate an increase of trunk fullness. However, a more detailed assessment is needed for a complete understanding. Additionally, we can measure the volume of the larger branches in the crown. Combining this measurement with the trunk volume, we can determine the total tree volume, an important and relatively accurate characteristic. This method can be employed to monitor the growth of large trees and assess their biological productivity and impact on the local climate [Chernevyy et al. 2024].

5. Conclusions

1. Effective methods for studying the biometrics of large, growing trees are currently limited. However, terrestrial photogrammetry using high-resolution digital cameras can be employed as a viable alternative.
2. This method enables efficient measurement of the tree trunk thickness at its lower section. Nonetheless, it is important to note that the results obtained from the upper part of the crown may exhibit some distortions.
3. By measuring the change in trunk thickness at a height of 1.3 meters and correlating this data with the form factor, it becomes possible to calculate the total volume of the trunk and assess its growth over time. This information can serve as the foundation for effective biometric monitoring.
4. Furthermore, the proposed method could facilitate the development of specialized software for digital cameras equipped with a matrix tilt sensor. Such software would enable the creation of transformed image models and digital data arrays essential for accurate calculations.

References

Chenbing G., Yonghong H., Jun Q., Lin X., Meihan Ch., Hongbing W. 2023. Image-based estimation of crown volume of individual street trees by plane calculation of angle disparity. Urban Forestry & Urban Greening, 86, 128029. https://doi.org/10.1016/j.ufug.2023.128029

Chernevyy Y., Tretyak P., Krynyts'kyy H., Savchyn A. 2024. Environmental and economic significance of big, old-growth trees. International Journal of Environmental Studies, 81(1), 475–488. https://doi.org/10.1080/00207233.2024.2314848

Coelho J., Fidalgo B., Crisóstomo M.M., Salas-González R., Coimbra A.P., Mendes M. 2021. Non-Destructive Fast Estimation of Tree Stem Height and Volume Using Image Processing. Symmetry, 13, 374. https://doi.org/10.3390/sym13030374

Marzulli M.I., Raumonen P., Greco R., Persia M., Tartarino P. 2019. Estimating tree stem diameters and volume from smartphone photogrammetric point clouds. Forestry: An International Journal of Forest Research, 93 (3), 411–429. https://doi.org/10.1093/forestry/cpz067

Monumental Trees. 2022 https://www.monumentaltrees.com/en/

Phattaralerphong J., Sinoquet H. 2005. A method for 3D reconstruction of tree crown volume from photographs: Assessment with 3D-digitized plants. Tree Physiology, 25, 1229–1242. https://doi.org/10.1093/treephys/25.10.1229.

Prodan M. 1968. Forest Biometrics, ed. 1. 460 p. https://www.sciencedirect.com/book/9780080124414/forest-biometrics

Sayn-Wittgenstein L., Aldred A.H. 1967. Tree Volumes From Large-Scale Photos. Photogrammetric Engineering. January, 69–73. https://www.asprs.org/wp-content/uploads/pers/1967journal/jan/1967_jan_69-73.pdf

Tretyak P., Tretyak N. 2020. Research tool: Biometrics of growing tree – 3. Web-service. http://econtsh.astra.in.ua/tree/tr_bm1.php?lang=en

Tsuryk YE. I. 2006. Taksatsiya dereva ta yoho chastyn: Navchal'nyy posibnyk [Taxation of a tree and its parts: Study guide], L'viv, NLTU Ukrayiny, 328 p.

Wu L.L., Chen Y., Feng Z.K., Tang X.H., Xu Z., Yan F. 2011. Research on Trunk Modeling Based on 3D Laser Scanning. Key Engineering Materials, 467–469, 1674–1679. https://doi.org/10.4028/www.scientific.net/kem.467-469.1674