THE EMPLOYMENT OF THE TERRESTRIAL DIGITAL PHOTOGRAPHS IN THE STUDY OF TREES' MORPHOMETRY

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Abstract

The paper proposes the employment of vertical terrestrial photographs analysis combined with drawings of the tree crown contour for the evaluation of the tree morphometric characteristics vegetating within stands. Digital image analysis software was used for tree crown contours extraction in two dimensional projections, also for the measurement of dimensional descriptors of stems and crowns. The results are compared with those obtained by applying classical measurements taken with hypsometer and stem calipers by means of t test, Cohen size effect index (d) and correlation coefficient r. Time allocation efficiency in terms of precision shows that the proposed method can be applied in dimension and shape analysis of the trees. The improvement of photographs' processing by means of specially designed software can facilitate the application of the proposed method in large scale activities during forest inventory or for the measurement of standing trees, which are specific for forestry.

Key words: tree morphometry, vertical terrestrial photographs, t test, size effect index, crown contour drawing, crown parametric shape.

INTRODUCTION

The methods and means employed in the study of tree morphometry are in a continuous change and adjustment. The need of a greater efficiency in the tree measurement and evaluation process is obvious, a fact highlighted by extensive literature produced on this topic. The actual trend is for the reduction of time needed for data sampling, the enhancement of explanatory power of the employed descriptive variables and indices in the case of dimensional measurements or shape evaluation of some morphometric components of the trees.

Tree measurements in ecological studies or in forestry practice include dimensional evaluations mainly of the stems and of the crowns. Several indicators including breast height diameter of the stem, total tree height, stem height up to the first branch, crown height, crown length are frequently employed in practice. These metrics are used during the elaboration of management plans, in tree stand modeling, growth rate quantification, inter and intra-specific competition assessment. Crown dimension, positioning and aspect are useful characteristics during the evaluation of forest health and tree selection for certain silvicultural interventions. Currently employed methods for the determination of the indicators are based on field measurements or reading from dendrometrical tables, many instruments and measurement devices being in use. Most frequently employed instruments for rapid evaluation of structural or functional parameters necessary in the monitoring process of silvicultural activities are: the hypsometer, the dendrometer, stems calipers, Bitterlich's relascope, etc. The errors produced by these instruments are situated in the interval 5-12.5% for tree heights, 2-11% for stem diameters (Clark et al., 1998).

Tree crowns shape is complex and highly variable, hence it is currently approximated visually, crown parameterization needing a great number of variables. Three dimensional structure, position within canopy, succession dynamics, crown variability in different species, to which one must add the influence of many biotic and abiotic factors are important aspects to keep account of when crown evaluation and classification is on focus. From methodological point of view, the first approach in the study of tree morphometry was statistical and mathematical modeling in order to establish relationships between morphological characteristics and functional aspects. Model were proposed on the relationship between foliar area and phloem area, relationships between stem diameter and tree biomass, between crown aspect and stem increment, models on the repartition of forces and loadings in the structural system of the tree, vertical distribution of the foliar area within crown and shoot biomass quantification, etc.

Tree growth within stands is an influential factor for the measurement efficiency reduction and a limiting factor in the application of many tree morphometry study methods. The change in quantitative approach of tree morphometry is relatively recent event: growing attention was paid to the study of crown shapes and to conditions created by light correlated with biomass accumulation aspects. Simplified models were obtained by assimilation of crown shape to a geometrical body of known dimensions. This category of studies has concentrated on the determination of crown volume which can be employed as competition estimator or evaluating device for the accessible natural habitats.

The quantification need of processes such as growth, survival and reproduction at tree population or community level implies finding more precise methods of individual tree architecture evaluation, which could be applied in a complex environment such as forest and also efficient from the point of view of time/number of measured trees rate. There are many references on methods for the determination of morphometric characteristics of the trees based on tomography, terrestrial or remote laser scanning (airplane or satellite), vertical terrestrial photographs.

The use of the terrestrial photographs for the quantification of tree crowns vertical projection became a popular method due to high quality, processing facilities and low cost (Rautianen et al., 2008). At the beginning, this technique was developed for the study of small plants and isolated trees. Quantified characteristics were crown volume, transparency and shape. For trees vegetating within stands, methodological approaches are based especially on the tree height measurement or the diameters at different stem heights (Clark et al., 2000).

The methods employed for tree terrestrial measurement using digital photographs are classified in two categories:

1. methods based on the analysis of 2D vertical projections of the trees (classical digital photographs is used, circular photographs obtained with fish eye objective or a drawing of the crown contour)
2. methods based on tree analysis in 3D representation (a set of classical digital photographs are employed or stereo photographs).

First category of methods relies on photographing and analyzing every inventory tree maintaining standard photography parameters. Work protocol includes tree photographing, empirical measurements useful for the calculation of errors during the comparative analysis of the methods, images rectification and the utilization of software for the calculation of parameters. Terrestrial photographs were erratically utilized in forestry from the beginning of XX-th century but the advent of digital photography and technological advances made them important instruments at large scale. Clark et al., (2000) propose and test the utilization of digital cameras for the determination of stem diameters of trees vegetating within stands. Their results confirm the fact that by photographs processing one can obtain precise measurements of stem thickness and stem volume as well as tree tilting, shape coefficients of the stems and a series of indices quantifying crown dimension and shape. Gaffrey et al., (2001) presents a historical essay on terrestrial photogrammetry and a synthesis of the errors implied by this category of methods. Dean (2003) use terrestrial photographs for the assessment of stem and branch volume of big trees obtaining an underestimation of 0.5 to 4% for branches. Pyysalo (2004) developed a photogrammetric method based on digital terrestrial photographs for the measurement of the geometrical shape and obtained the morphometric parameters of a tree. The equipment contained a digital camera, a tripod, hypsometer, compass, measuring tape and adjustable vertical scale. Maximum vertical and horizontal errors were around 0.4m. Another method based on the simplification of crown architecture by 2D projection analysis is based on the drawing of the crown contour in order to obtain expected parameters. Such an approach used Hussein et al., (2000) by means of a simple device named crown window. The method is rapid and the degree of accuracy depends on the rigor of the operator.

Second category of methods relies on the 3D model construction using a set of photographs shot on different directions around the tree or stereo images. Shlyakhter et al., (2001) proposed a construction algorithm for the generation of 3D image of the tree by introducing in analysis system of 4-15 images which cover uniformly at least 135 degrees around the tree .Camera position with regard to the tree is known. Construction process contains is developed in four steps: image segmentation, visual hull construction, (the grid approximates 3D tree shape), tree skeleton construction which incorporates the stem and first level of branching. Phattaralerpong & Sinoquet (2004) tested the possibility of the utilization of a set containing eight photographs for the calculation of isolated trees crown volumes. Reconstruction method was based on the estimation of tree height and maximum crown diameter on each photograph, tracing a 3D rectangular frame around a crown with known dimensions, the calculation of crown volumes.

It is worth to mention that the majority of published papers focus on methodology by testing vertical terrestrial photographs from the point of view of efficiency and information quantity obtained from a reduced set of trees. In order to ensure a large scale applicatibility of crown and stem description in hierarchical structures from individual, population and species level, implies finding an appropriate method for crown delimitation on photographs within stands where crowns overlap occur frequently.

The present paper proposes a combination of terrestrial vertical photographs with Hussein's et al. (2000) method of the aboveground tree architecture morphometric analysis, for trees vegetating within stands. Results obtained after photographs' and contour drawings' processing were compared with measurement results which are regularly utilized in silvicultural practice. The comparison was performed using statistical t test on pairwise data, Cohen size effect index, correlation coefficient r and the estimation of errors. The obtained crown and stem estimations are more detailed and closer to real tree dimensions and shapes, even if they are obtained on 2D projections. The method permits the estimation of usable biomass from practical point of view, beginning with crown shape as indicator, which makes field work easier and is a reliable estimator.

MATERIAL AND METHOD

The aim of the study was to test method efficiency, hence pure *Quercus petraea* coppice stands, vegetating under similar site conditions, were selected. Trees' age varied in the interval of 55-100 yr, stem diameters between 24 and 40 cm accordingly, the stands varied with respect to age and dimension structure corresponding to developmental evolution. Management units where study sites has been selected are affiliated to forestry department Cluj, forestry district Cluj, production unit IV Făget, management unit 108A, 109B and 111A. 30 trees were randomly selected in random walk, corresponding to stem diameter categories 24 cm (management unit 108A), 28 and32 cm (management unit 109B), 36 and 40 cm (management unit 111A).Trees were selected to be situated at least at 100m from the forest edge in order to catch the characteristic within stand crown shape. Dominant and co-dominant trees according to Kraft classification were selected. To avoid variability induced by terrain topography in tree morphometry, only trees positioned on plateau were selected.

Every tree was photographed with Konica Minolta camera DiMage Z5 using standard settings. However, in stands with closed canopy, taking tree vertical photographs becomes more difficult due to crown overlapping. In order to overcome these inconveniences, drawings were performed on transparencies, from same positions used for photographing and same orientation. The only different parameter was the distance eye-drawing board which was different from the focal distance of the camera. This inconvenience is eliminated at the moment of the overlapping of the photograph and the corresponding drawing, using characteristic points of the crown shape, common to photograph and to drawing. Efficiency testing of the method was performed by measuring with Suunto PM-5/1520 hypsometer total height (h), height to first branch (h_{el}), crown height (h_{cor}): stem calipers were used to measure stem diameters at dbh. Field measurements were compared with digital measurements performed on photographs and drawings.

Standard conditions for photographing and drawing were: distance tree-operator of 20m, photographing height (camera-ground) was of 1.2m, angle formed by the objective axis and horizontal plane of 20±4 degrees, photograph taking direction was determined with the compass. The dimensional marker, useful during the process of photograph rectification, was vertical scale. 6 points with known coordinate metrics were obtained: 4 at the base of the tree, one at the inferior limit of the crown and one at the superior limit of the crown (Photo 1). Every tree must be correctly framed before taking the photograph to include the base and the top. The obtained images had 72 DPI resolutions (2272x1704 pixels). Focal distance of the camera was set to 6 mm and exposure time of 1/60 sec. The photographing vertical angle was measured using the hypsometer attached to the objective of the camera. After camera setting on the tripod and of the drawing device, 4 photographs were taken and the crown contour was drawn on the transparency for each tree. 600 photographs resulted from which only 300 were selected, a photograph for each tree, considered to be optimal from the point of view of maximal clarity, appropriate for further complete digital processing. The field drawings were scanned at 300DPI resolution using Mustek 1200CP scanner and the photographs were transferred on computer in a data base. For proper identification and data management, to each tree a code was attached composed of a digit and a letter (ex: tree 5v).

The crown contour was overlapped on the corresponding photograph using at least 3 of indicator points on the drawing and on the photograph (crown base, inflexion points, top of the tree, etc.). This is useful as a marker especially of invisible on the photograph crown portions. Real contour was obtained by manual vectorization, resulting a precise visualization of crown irregularities in 2D projection (photo 2).

During photographing, image plane was not parallel with the plane including the tree axis therefore a rectification correction had to be applied. The employed software was ASRix v2.0 (Karras and Mavrommati, 2001), which permits the rotation and scaling of the photograph, the elimination of the errors due to photographing angle and the transformation of the image coordinates measured in pixels in real metric coordinates. These transformations were performed photographing objects of known dimensions, usually buildings. In our case, two marked belts (markings at every 20 cm distance) functioning on the principle of leaded string were employed, placing them at right and left side of the measured crown on photographing direction to correct vertical deformations of the image. The distance between the two belts was measured at the top and the base of the tree to obtain a metric marker and to assess horizontal plane deformations (photo 3). Due to macro-relief, to variable height of the trees, it was not always possible to frame the image under same photographing angle. In order to eliminate this inconvenience, photographs were taken of the tree with attached belts using three angles (18, 20 and 22 degrees) (Fig 1). Resulted grids were overlapped on the tree photographs under same geometrical parameters.

On rectified photographs containing the crown contour, total tree height (h), stem height to the first branch (h_{el}), crown height (h_{cor}) and dbh diameter ($d_{1,3}$) were measured with the help of image processing software Image Tool for Windows v.3 (Wilcox et al., 2002). The comparison of field determined measurements and resulted after image analysis was performed with pairwise t test using KyPlot ver. 2.0 beta 15 software (Yoshioka, 2000), size effect index (d) and correlation coefficient r.

T test was applied grounded on the premise that the variables are normally distributed and the variances were homogenous. The test confirms, based on the rejection of the null hypothesis that there is a significant difference between the means of the compared variables.

In order to assess the effect of the independent variable on the means difference, Cohen size effect index was calculated and the correlation coefficient. Size effect index is a numerical value which assess the power or the magnitude of the relationship between the variables regardless to the fact of existence (or not) of causal link. The corresponding equation (Cohen, 1988) is:

$$d = \frac{M_D}{S_D} = \frac{M_D}{\sqrt{\frac{SS_D}{n-1}}} = \frac{\frac{\sum D}{n}}{\sqrt{\frac{\sum D^2 - \frac{(\sum D)^2}{n}}{n-1}}}$$

Where:

d - stands for the size effect of pair wise t test

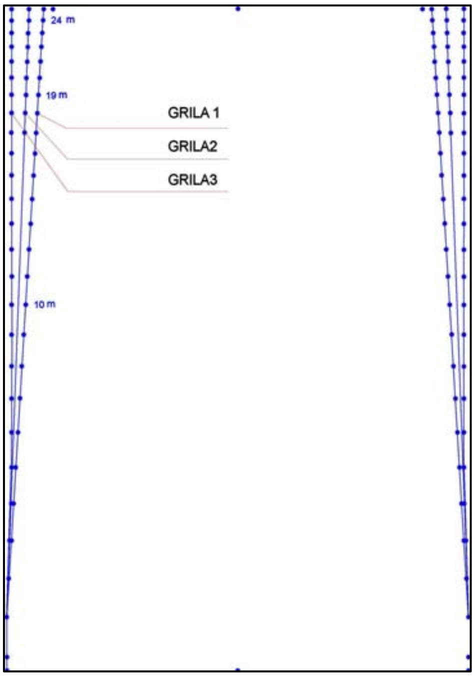
M_D - stands for arithmetic mean of D values

S_D - stands for variance of D values

SS_D - stands for D values sum of squares

D -stands for differences between corresponding values of the selected variable for analysis

n - stands for sample size.



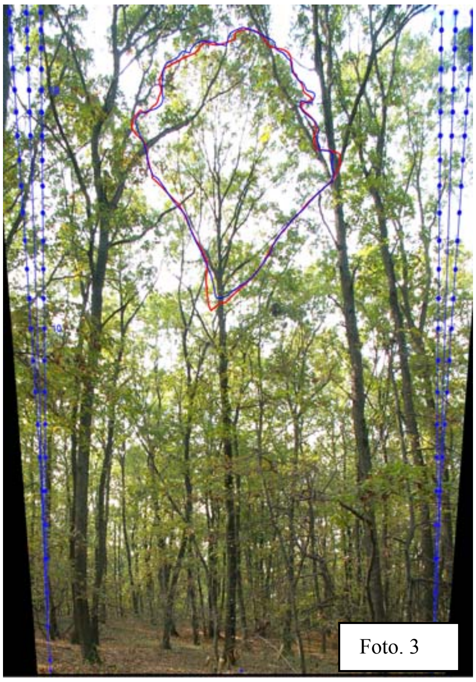


Photo 1 Photograph taken with dimensional markers for known metric coordinates.
Photo 2 Crown contour drawn in the field (—), real contour vectorized (—)
Fig. 1 Grids employed in the rectification process
Photo 3 Modified photograph after rectification.

The interpretation of the results followed the scale proposed by Thalheimer and Cook (2002) with 6 intensity levels ($-0.15 \le d < 0.15$ negligible; $0.15 \le d < 0.40$ small effect; $0.40 \le d < 0.75$ medium effect; $0.75 \le d < 1.10$ high effect; $1.10 \le d < 1.45$ very high effect and over 1.45 extremely high. Pearson correlation coefficient r, gives information on the existence of a functional relationship between variables as well as the magnitude of this relationship.

Regardless to the employed method, the measurements imply errors which can be of objective nature determined by measurement devices technical characteristics, focal distance adjustment or of subjective nature such as visual acuity of the operator, repeated measurement induced fatigue. In the present study, two types of errors occurred: field measurement errors and data processing error (digital photographs or drawings).

Field measurement errors include: erroneous determination of the operator-tree distance, improper measurement of the tilting angle of the camera, errors induced by micro-site conditions, errors induced by involuntary movements of the camera during exposition. There are errors induced by improper exposition which cause imprecise localization of the indicator points on the photographs.

Errors due to digital images processing include; marker measurement errors, heights measurement errors for which no field markers were used, measurement errors due to crowns' overlap.

Errors induced by camera were: lens distortion, radial distortion of image plane, technical performance of the device, etc.

The current use of performing high resolution, digital cameras which are accessible at the moment lead to the elimination of the errors, permit clarity and deepness of the sampled images. They make possible a precise localization of the analyzed shape details. For comparison, of literature cited results with our own results, the error calculation method of Gaffrey et. all. (2002) was employed:

Equation: $$\overline{\Delta x} = \frac{1}{n}\sum_{i=1}^{n}(\tilde{x}_i - x_i) \qquad \overline{\Delta x_{\pm}} = \frac{1}{n}\sum_{i=1}^{n}\left|(\tilde{x}_i - x_i)\right|$$

$$S_{\Delta x} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\Delta x_i - \overline{\Delta x})^2} \qquad S_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\tilde{x}_i - x_i)^2}$$

Δx - stands for measurement error, $\overline{\Delta x}$ stands for error mean, $S_{\Delta x}$ stands for standard deviation of the errors; $\Delta x = \tilde{x} - x$ stands for difference between measurements performed on the photographs and the corresponding reference measurements in the field.

Results

The existing differences between classical method for trees' measurement employed in forestry and the method based on combined vertical terrestrial photographs and crown contour drawings are highlighted by statistical tests and measurement errors calculations.

Table 1 shows means, standard deviations and general results of t test at the appropriate significance level. Comparisons were performed on paired data from the same diameter category, for 4 variables (h, h_{cor}, h_{el}, $d_{1,3}$), usually employed in classical biometrical studies. The table also presents the values of Cohen size effect index and of the correlation coefficient.80% of the t test results are not significant, 155 are marginally significant and 5% are significant. Greatest differences appeared in the case of h_{el} due to imprecise delimitation on photographs, the inconvenience being overcame in drawings where the exact position of the lowest branch could be marked. All analyzed variables displayed high positive correlation, over 0.83. Size effect index had negligible and small values for most of the situations, only 15% for means. From 20 analyzed combinations (field measurements-photographs) only four contradict null hypothesis. Overlap degree of the distribution GS (table 2) was calculated for these cases. Mean overlap was of 68.5% and the explanation was the crowns; overlap which make invisible the top or the base of the crown on photographs.

The errors are inherent to classical field measurements, a fact highlighted by the results of comparisons; however, values greater than 85% of the GS values indicate differences of the analyzed distributions which are not significant.

Table 1

Comparisons between field measurements and photographs of four biometric variables h, h_{cor}, $h_{el,}$ $d_{1,3}$ using pairwise t test, size effect index, correlation coefficient, Software: KyPlot ver. 2.0, beta15

	Ø (cm)	Mean	SD	t(0,05)	t(cal)	P (t<=tcal)	Significance level	d	r
Total height (h)									
Field	**24**	19,058	1,625	2,0452	0,1750	0,8623	**N.S.** (P>0.05)	0,03	0,830
Photographs		19,028	1,631						
Field	**28**	20,116	1,704	2,0452	1,9749	0,0579	**N.S.** (P>0.05)	0,16	0,960
Photographs		19,944	1,605						
Field	**32**	21,050	1,707	2,0452	2,6689	0,0123	* (P<=0.05)	0,48	0,943
Photographs		20,765	1,470						
Field	**36**	22,275	1,134	2,0452	2,0426	0,0503	**N.S.** (P>0.05)	0,27	0,934
Photographs		22,124	1,063						
Field	**40**	23,100	1,636	2,0452	1,9396	0,0622	**N.S.** (P>0.05)	0,29	0,898
Photographs		22,881	1,806						
Stem height to first branch (h_{el})									
Field	**24**	7,692	3,560	2,0452	-2,1519	0,0399	* (P<=0.05)	-0,39	0,997
Photographs		7,804	3,602						
Field	**28**	8,683	3,065	2,0452	-1,6419	0,1114	**N.S.** (P>0.05)	-0,20	0,992
Photographs		8,797	2,982						
Field	**32**	7,992	2,203	2,0452	-3,6064	0,0012	** (P<=0.01)	-0,65	0,995
Photographs		8,158	2,309						
Field	**36**	7,483	3,542	2,0452	-1,9473	0,0612	**N.S.** (P>0.05)	-0,25	0,998
Photographs		7,566	3,514						
Field	**40**	9,400	2,785	2,0452	-1,2512	0,2209	**N.S.** (P>0.05)	-0,22	0,991
Photographs		9,489	2,849						
Crown height (h_{cor})									
Field	**24**	10,650	1,875	2,0452	-1,9866	0,5565	**N.S.** (P>0.05)	-0,27	0,986
Photographs		10,756	1,919						
Field	**28**	9,978	2,001	2,0452	-1,5526	0,1314	**N.S.** (P>0.05)	-0,28	0,980
Photographs		10,091	1,904						
Field	**32**	10,000	1,759	2,0452	-2,3177	0,0277	* (P<=0.05)	-0,42	0,990
Photographs		10,105	1,693						
Field	**36**	9,908	1,823	2,0452	-1,9051	0,0676	**N.S.** (P>0.05)	-0,24	0,992
Photographs		9,904	1,805						
Field	**40**	10,375	1,377	2,0452	-1,3571	0,1852	**N.S.** (P>0.05)	-0,24	0,961
Photographs		10,475	1,447						
DBH ($d_{1,3}$)									
Field	**24**	25,093	1,085	2,0452	-0,9878	0,4360	**N.S.** (P>0.05)	-0,14	0,880
Photographs		25,168	1,033						
Field	**28**	29,550	0,986	2,0452	1,9231	0,0643	**N.S.** (P>0.05)	0,26	0,960
Photographs		29,440	1,108						
Field	**32**	32,989	1,023	2,0452	0,5779	0,5678	**N.S.** (P>0.05)	0,10	0,873
Photographs		32,920	1,310						
Field	**36**	36,976	1,139	2,0452	-0,4738	0,6392	**N.S.** (P>0.05)	-0,08	0,883
Photographs		37,024	1,150						
Field	**40**	41,206	1,330	2,0452	-0,1320	0,8959	**N.S.** (P>0.05)	-0,02	0,897
Photographs		41,221	1,439						

The interpretation given to size effect index and to overlap degree of GS distributions consists in stating that the differences between field measurements and photographs for combinations rejecting null hypothesis correspond to the interval of small and average values. This inconvenience can be avoided by marking on the drawings the position of first branch.

Table 2

Analysis of obtained values of Cohen index and overlap degree of distributions GS for t test rejected null hypothesis cases

Location	Variable	Ø (cm)	GS %	Semnificația lui d
P.U. IV Făget	h (m)	32	68	Medium size effect
	h_{el} (m)	24	74	Small effect
		32	60	Medium size effect
	h_{cor} (m)	32	72	Medium size effect
Mean value			**68,5**	

Using the method recommended by Gaffrey et al., (2001) of measurement error calculation several metrics were calculate (see general equation) in order to compare our results with existing literature results. Table 3 presents these results corresponding to locations and diameter categories. Due to logistic and field measurements limitations as well as technological limitations of the employed devices, values obtained by several authors are only of orientate nature. The method proposed by the current paper relies on error analysis taking into account the fact that results come from a population of trees and not few individuals asp resented in the literature.

Table 3

Determination of mean errors, standard deviation of measurement errors and general mean errors for the analyzed biometrical variables h, h_{cor}, h_{el}, $d_{1,3}$, compared by two employed methods

Analyzed variables												
	h (m)			**h_{el} (m)**			**h_{cor} (m)**			**$d_{1,3}$ (cm)**		
Location: P.U IV Făget, F.D. Cluj												
Ø (cm)	$\overline{\Delta h}$	$S_{\Delta h}$	S_h	$\overline{\Delta h_{el}}$	$S_{\Delta hel}$	S_{hel}	$\overline{\Delta h_{cor}}$	$S_{\Delta hcor}$	S_{hcor}	$\overline{\Delta d}$	$S_{\Delta d1,3}$	$S_{d1,3}$
24	0,03	0,93	0,83	-0,11	0,28	0,30	-0,09	0,31	0,32	-0,08	0,51	0,52
28	0,17	0,47	0,50	-0,11	0,37	0,39	-0,11	0,39	0,41	0,08	0,29	0,30
32	0,29	0,58	0,64	-0,17	0,25	0,30	-0,10	0,24	0,26	0,07	0,64	0,64
36	0,15	0,40	0,43	-0,08	0,23	0,24	-0,09	0,24	0,26	-0,04	0,54	0,55
40	0,23	0,57	0,61	-0,09	0,38	0,39	-0,10	0,40	0,41	-0,02	0,63	0,63
Media	**0,17**		**0,60**	**-0,11**		**0,32**	**-0,10**		**0,33**	**0,002**		**0,53**
SD	**0,10**		**0,15**	**0,03**		**0,07**	**0,01**		**0,08**	**0,07**		**0,14**

According to Gaffrey et al. (2001) method, mean errors for height measurements were of 0.25m (Takahashi, 1997), of -0.02 m and 0.08 m (Gaffrey et al., 2001) as compared to 0.60 for total height, -0.11 for stem height to first branch, -0.10 for crown height in our study. In the case of the diameters, mean errors were 0.16cm and 0.14 cm at Gaffrey et al., (2001) compared to our results of 0.002 cm

The results obtained by other authors in the case of the general error mean of heights were 0.16m and 0.39m (Lebrun, 1974), 0.19 m (Račko, 1983), 0.8 m (Kraibig, 1972), 0.62 (Takahashi, 1997) as compared to 0.60 m (total height), 0.32 (stem height to the first branch), and 0.33 m (crown height) in the present study). In the case of diameters, general mean errors are 0.35 and 0.48 cm (Muller, 1931), 0.35 and 0.6 cm (Krebig, 19720), 0.4 and 0.9 cm (Lebrun, 1974), 0.6 and 0.4 cm (Račko, 1983), 0.46 (Takahashi, 1997) as compared to our results of 0.53 cm.

It is worth to mention that during the present study, a different camera was employed and different photographs processing methods as compared to data already existing in the literature (digital camera, film recording cameras, and stereo photographic cameras). One important parameter of efficiency for tree morphometric analysis is time.

The results are presented in table 4 on stages and operations. There is not included the movement time from a tree to another and the time spent on statistical analysis.

Table 4

Timing of measurements and analyses per tree

Work stages	Operations	Average duration (min)
Field work	***Stand selection***	**4**
	- stand selection	
	-establishment of photographing direction	
	-clearing at ground level (to avoid overlapping)	
	-stem diameters and tree heights measurements	
	Acquiring the photographs	**7**
	- measurements of operator-tree distance	
	- setting the tripod	
	- setting of camera and drawing device	
	- camera adjustment and photograph shooting	
	Contour drawing	**1**
A. Activities' timing/tree		**12,00**
Laboratory stage	Saving photographs on computer	**0,2**
	Raw data ordination and classification	**0,5**
	Image processing	**11**
	Extraction of real contour	
	- vectorization of the drawings	
	- overlap of the vectorized image on the corresponding photograph	
	- tracing real contour	
	Morphometric analysis of crowns and stems	
	- extraction of variables obtained with Image Tool software	**0,3**
	- data centralization	**0,75**
B. Time needed for a tree		**12,75**
Total time allocation for measurements and analysis/tree		**24,75**

Necessary time for data saving, ordination and processing of photographs resulted from tree analysis using the computer with next characteristics: AMD Athlon 64 1200+processor, 2.5 GB DDR2 memory, HDD Samsung 7200 RPM SATA hard disk. Photographing and drawing in field requires 12 minutes on average. Average time allocated to image analysis and processing per tree was 24.75 minutes. For 150 analyzed trees during this study, average allocated time was 61.88 hours. This time volume is correlated with high information quantity obtained from image analysis. Further developments on these data were fractal analysis Elliptic Fourier Analysis, multivariate analysis. All these results converged to the description of the parametric shape of the crown at species level, calculation of crown volumes and establishment of relationship between crown dimensions and biomass accumulated in the stem.

RESULTS AND DISCUSSIONS

The shape and dimensions of an organism are variables employed in the morphological description. The variation of these descriptors has important ecological and physiological significances. One of the central morphometry problems is the separation of shape from dimensional differences (Rohlf & Bookstein, 1987) considering the shape as a better descriptor for morphological properties of an organism (Sunberg, 1989) because dimensions are more variable at ontogenentic and phylogenetic scale. Intuitively, the shape is the geometry of a configuration (Marcus et al., 1996). Trees are characterized by considerable morphometric and structural plasticity. At individual level, there cannot be found two trees with identical architecture. Tree architecture is the result of genetic heritage and of the interaction between trees and environmental factors, both abiotic and biotic.

Morphometric data collection, processing and interpretation permit correct management decisions a better understanding of forest processes and finally, data standardization and centralization in a data base. Structural and temporal perspectives on development trends and structural models are obtained (Rennolls et al., 2002). Obtained results depend on measurement types and accuracy. Enhanced precision of the tree morphological, structural, physiological parameters quantification needs utilization of performing measurement instruments and devices, adapted to study type.

In order to make more efficient the evaluation process of tree morphometry from the point of view of variables' type and number, the use of terrestrial vertical photographs was tested. The extraction of dimensional characteristics on photographs and the comparison with classical measurements using the hypsometer and stem calipers revealed the existence of negligible differences. Greatest differences were reported in the case of stem height to the first branch due to the difficulty to establish on the photograph the exact position of the first branch insertion. In most of the cases, the branch was too thin to be observed. This error could be eliminated marking on the drawing of the stem base, of stem height to first branch and crown height, making easier the measurements on the photographs. Errors calculated for h, h_{cor}, $h_{el,}$ $d_{1,3}$, correspond to the reported values in the literature, a fact that stresses the capacity of the method to obtain precise measurement data. The analysis performed on tree diameter categories shows that there is no trend in error variability linked to developmental stages of the stands. Total height general mean error has a maximum value of 2.84% in the case of the 150 analyzed trees, for stem height to the first branch it was 3.87% 3.24 for crown height and 1.59 for dbh. The combination of photographs and contour drawings facilitates the application of the method in dense stands, the obligatory condition being the visibility of tree tops and base and appoint on crown sides. As stand density grows, crown overlapping also grows and consequently, vector length of the contour drawing.

Spatial distribution is an important factor in tree architecture and also in the application of the proposed method, being directly correlated with tree competition. In the case of coppice, multiple stems induce crown deformations and asymmetries and high variability of their volumes. Under these circumstances, frequent overlapping of the crowns make more difficult the process of crown individualization on photographs and drawings. Tree morphometry for coppice trees is more variable than in the case of seed originating tree. Possible causes are differences in growth rates of young shoots, crooked conformation of the stems, more pronounced spatial aggregation, and frequent epicormic growth due to non-uniform light regime within stands. The investigated stands are managed and highly artificial, this fact being observed also in crown architecture modeled by silvicultural interventions and their frequency, periodicity or the developmental stage when they have been applied. Table 5 presents the dimensional and shape descriptors that can be determined by the proposed method and separated, for rapid studies, a simplified method using only contour drawings and usual biometric measurements.

The disadvantages of the method is the lack of applicability in young or dense stands, the lack at the moment of a software permitting automatic photographs' processing, the obtained measurements are obtained from 2D projections analysis, during rectification different grids are employed and different cameras.

The advantages of the method are the possibility of detailed description of crown shape and dimensions or tree stem using one standardized photograph. It is a non-destructive method, easy to use in the field and not necessitating expensive instruments. The precision is high and can even grow with a more competitive camera. Photographs can be saved in a data base and retrieved in further studies of growth rates or evaluations of different influential factors on stands or trees.

In conclusion, a non-destructive, rapid, with accessible technique method for the study of aboveground, within stand, tree morphometry was proposed. The method can be used in forest inventories, forest health monitoring, and research/practice activities. The future goal to improve the method is the conception of software for the automatic determination of shape and dimensional descriptors on terrestrial vertical photographs which would reduce analysis time and would make the method to apply to large scale investigations.

Table 5

The dimensional and shape descriptors that can be determined by the proposed method and separated, for rapid studies

<table>
<tr><th>Detailed studies on small number of trees</th><th>Rapid studies on large number of trees</th></tr>
<tr><td>Vertical terrestrial photographs
+
Crown contour drawings
+
Usual biometric measurements</td><td>Crown contour drawings
+
Usual biometric measurements</td></tr>
<tr><td colspan="2">Stem morphometry</td></tr>
<tr><td>- stem diameters at different heights
- shape coefficient of the stem
- estimation of length increments of the stem
- estimation of total or partial stem volume
- calculation of stem tilting
- highlighting of external stem defects</td><td></td></tr>
<tr><td colspan="2">- heights' measurements: total height, stem height to first branch, crown height</td></tr>
<tr><td colspan="2">Crown morphometry</td></tr>
<tr><td>- tilting angle of branches
- evaluation of crown transparency, defoliation or discoloration level, the presence of dieback</td><td></td></tr>
<tr><td colspan="2">- crown length measurement
- estimation of crown diameters at different heights
- calculation of areas, perimeters and volumes
- shape characteristics of the crown: elongation, compaction, fractal exponent, determination of crown parametric shape, crown symmetries and asymmetries
- finding crown centroid
-using a set of crown photographs and contour drawings of the same tree, one can reconstruct it in 3D</td></tr>
</table>

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