Guiding Field Measurement of Pine Tree Crowns: A Geometric Shape Comparison Using Drone Imagery

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Abstract

This paper examines various geometric shapes to determine the most suitable one for calculating tree crown area in field measurements. The study was conducted in an Eldarica pine plantation forest, which was digitally mapped using RGB images captured by a Phantom 4 Pro drone. Tree crowns were manually digitized (MD) from these images to serve as reference data. Field measurements, including the large and small crown diameters, were collected to evaluate crown areas derived from different geometric shapes. The geometric shapes considered were: Oval with Both Diameters (OBD), Circle with Small Diameter (CSD), Circle with Large Diameter (CLD), and Circle with Mean Diameters (CMD). Three analyses were performed to assess the results: correlation analysis (R^2), relative root mean square error (RRMSE), and shape analysis, which included overestimation (OverID) and underestimation (UnderID) indices. The results revealed that the choice of geometric shape significantly impacts the accuracy of crown area calculations. The OBD model based on the outer boundary diameter yielded the best results with RRMSE = 0.29, R^2 = 0.84, OverID = 0.18, and UnderID = 0.23, followed closely by the CMD method. In contrast, the CSD and CLD models performed less effectively, with RRMSE = 0.52, R^2 = 0.42, OverID = 0.11, UnderID = 0.35 (CSD), and RRMSE = 0.59, R^2 = 0.37, OverID = 0.46, UnderID = 0.22 (CLD). These differences in performance are likely due to the inclusion of empty spaces within the crown area in some models. However, the findings of this study are not universally applicable to all tree crown area calculations. The geometric shape used for crown area estimation must align with the structural characteristics of the forest and the specific geometry of the tree species under consideration.

1. Introduction

Over the past decades, significant progress has been made in demonstrating the capabilities, limitations, and applications of remote sensing in the field of forest monitoring. one of this progress is the use of remote sensing data and techniques for characterization of forest structure (Panagiotidis et al., 2017). Furthermore, remote sensing helps forest monitoring despite challenges such as vastness, inaccessibility of some areas, and difficulties in reaching the location (Fassnacht et al., 2024). So that before the advent of remote sensing, it was difficult to record the location and information of individual trees over large area (Guimarães et al., 2020). So, physical parameters of trees have not been properly assessed and documented in the past. One of these parameters is tree crown area.

Tree crown is the mass of foliage distributed on branches that grow outward from the tree trunk (Porté et al., 2000) and the crown width is the horizontal distance from the center of the tree trunk through the azimuth points of the crown (Sharma et al., 2017). Since the crown is the main source of primary productivity, it indicates the general health and performance capacity of the tree. The shape and area of the crown of trees are two of the most influential parameters controlling the physiological processes of photosynthesis, respiration, and transpiration (Sumnall et al., 2024). Various physiological performance, which are crucial for tree growth and development, such as light absorption, carbon dioxide absorption, oxygen release, and evapotranspiration, are carried out in the crown (Panda et al., 2016). Also, Crown dimensions are closely related to foliage area and crown volume (Gallardo-Salazar et al, 2020). On the other hand, Crown measurements are effective for determining many quantities as well as determining tree performance at the growth stage, stability, and yield of trees (Barbosa et al., 2021). Crown cover is also correlated with crown dimensions and Leaf Area Index (LAI). Therefore, it can be an important predictor of plant productivity, help in the monitoring of tree growth (Stenberg et al., 1994). Crown size is also significantly correlated with the growth and biomass of other tree parts, whose dimensions are often used as predictors in forest models, biomass models, and growth models (Tahvanainen and Forss, 2019). Since, with constant change in crown shape and area, the trend in the models is constantly changing, so requires precise monitoring of the shape of the crown area along the time.

The shape and area of tree crowns are constantly changing due to various factors, including growth process, age, sunlight utilization rate, and surface microclimate of each area (Menéndez-Miguélez et al., 2021). This difference has caused challenges in estimating the accuracy of crown extraction using photogrammetry, point clouds, classification, and segmentation methods. There is usually no fixed approach to calculating the crown area of trees in the field. So that sometimes a circle and sometimes an oval are used as geometric shapes.

In this study, Manual Digitization (MD) of RGB drone images was used as reference data. Then, the two large and small diameters of the crowns of Eldarica pine trees were carefully measured. In the next step, four geometric shapes including: a Circular with Small Diameter (CSD), a Circular with Large Diameter (CLD), a Circular with Mean Diameter (CMD), and Oval with Both Diameters (OBD) were used to measure the crown area. Finally, the estimated areas were assessed by correlation (R^2), error (RRMSE), and shape (overID and underID) parameters (Figure 1).

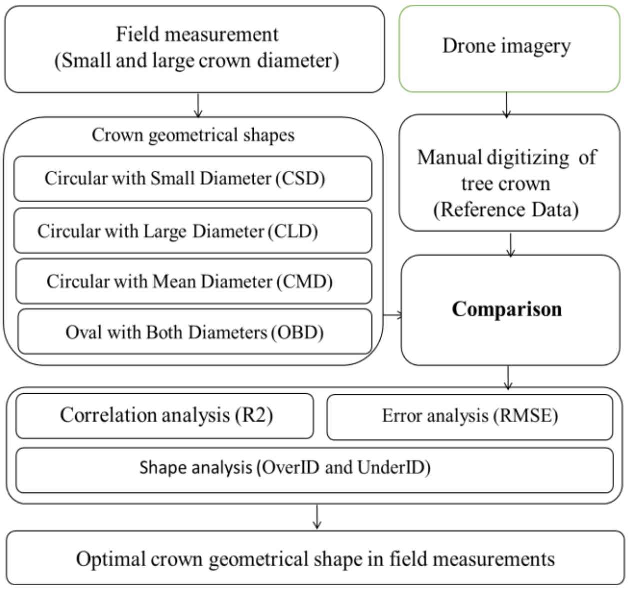

Figure 1. Flowchart of research.

2. Materials and Methods

2.1 Study area

North Khorasan Pardisan Park (37° 57' 28" N and 57° 49' 25" E) is located at an average height of 1080 m above sea level. The region is cold and semi-arid and has an altitude range between 1111.9 to 1036.5 m. The average rainfall and temperature in the period of 2011-2021 was 260 mm and 15 °C, respectively. Trees in this area were planted in different years, which has led to differences in the sizes of their physical parameters. The slope in this area also varies greatly, creating different shaded and sunny slope exposition. Due to the presence of animals, access to the area by people is only possible with legal permits, reducing the impact of human presence. The area is covered by Eldarica pine. Figure 2 shows the study area.

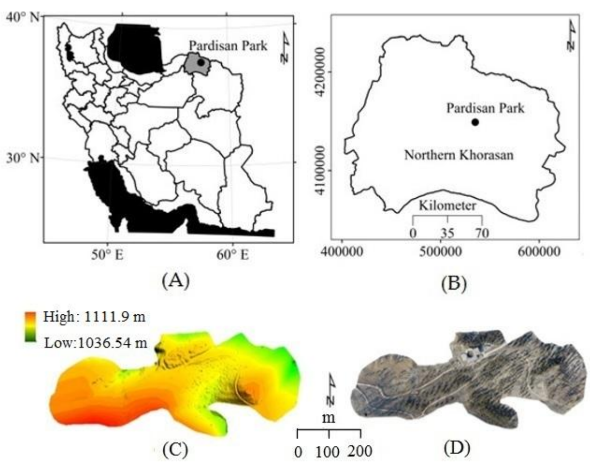

Figure 2. Iran (A), North Khorasan Province (B), DEM (C), Orthophoto (D).

2.2 Field Data Collection

All trees in the study area (324 trees) were accurately measured over a period of five days. For this purpose, the positions of all trees were first recorded using a dual-frequency (model iRoG3B) Global Positioning System (GPS) that connected to the Shamim system (Integrated Property Positioning Network in Iran). The horizontal and elevation accuracy was set on 0.45 cm and 0.8 cm respectively. In order to survey trees correctly and uniformly within the range of horizontal and elevation accuracy, the permissible accuracy range (horizontal accuracy of less than 0.5 cm and elevation accuracy of less than 1 cm) was defined in the device. Also, by activating the device's tilt sensor, the correct position of each tree was accurately recorded to eliminate any human error caused by the researcher's misalignment of the device during the surveying. Then, quantitative characteristics of each tree, including two perpendicular crown diameters (small and large) measured by using a standard meter (±1 mm). The two perpendicular crown diameters were used to estimate crown area.

2.3 Drone Imaging

In this study, Phantom 4 Pro drone with RGB images were used. The drone has a three-axis gimbal to prevent any vibration and create a proper balance of the camera in various image acquisition missions. Image collection in this study was carried out at a height of 40 meters and with overlap and sidelap of 80 and 40 percent respectively. Then, all images were visually inspected to confirm their blurring and light scattering at the edges of the image. Also, environmental conditions, including light winds with a speed of less than one knot and clear air, were considered in choosing the flight day. More specifications of the camera used and the digital aerial images received are listed in Table 1.

Image format	JPG
Color combination	RGB
Saturation	Normal
Clarity	Normal
Contrast	Normal
UAV speed	4 m/s
Camera tilt control mode	Active
Positioning system	GPS/GLONASS
Camera maker	DJI
Camera model	FC6310
Focal length	24 mm
Image dimensions	5472×3448 Pixel
The size of each image	20 Megapixel
shutter speed	1/160 Second
Horizontal resolution	72 dpi
Vertical resolution	72 dpi

Table 1. Specifications of the UAV camera and digital aerial images.

The imaging was done on March 5, 2020 at 2:30 PM (952 images). Also 14 ground control points were used to georeferenced the images. In order to prevent some errors, including stretching during imaging, a speed of 4 meters per second was used.

2.4 Manual digitizing of crown area and calculation of crown area

In order to evaluate the accuracy of the estimated pine tree crown area, crown manually digitization was used on RGB orthomosaic.

2.5 Accuracy assessment

In order to evaluate the accuracy of the results, three indices including: Correlation analysis (R^2), Relative Root Mean Square (RRMSE) analysis (Equation 1) and shape Analysis (overID and underID) (Equation 2 &3) were used.

$$RRMSE = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y})^2}{\sum_{i=1}^{n}(\hat{y}_i^2)}} \quad (1)$$

Where y_i = real crown area
$\hat{y}_i$ = estimated value
n = number of samples

A RRMSE value of zero indicates that the method is efficient. The RRMSE, parameter alone cannot provide a suitable estimate. Therefore, the similarity of the tree crown area must estimate. For this purpose, two parameters, over-identification error (OverID) and under-identification error (UnderID) (Figure 4) were used to examine the tree crown shape (Equation 2 and 3).

$$\text{OverID}(O_i) = 1 - \frac{\text{area}(O_i \bigcap R_j)}{\text{area}(O_i)} \quad (2)$$

$$\text{UnderID}(O_i) = 1 - \frac{\text{area}(O_i \bigcap R_j)}{\text{area}(R_i)} \quad (3)$$

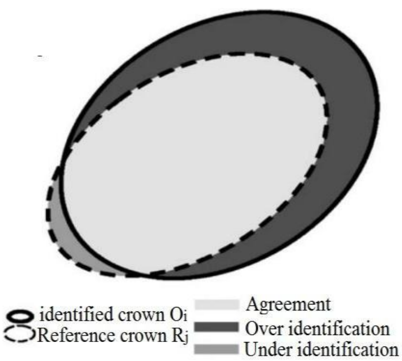

Figure 4. OverID and OverID Parameters.

Values close to zero indicate a high agreement between the tree crown extracted from the geometric algorithm and the Manual crown digitizing (reference data). The total error is calculated using Equation 4.

$$\text{total error}(O_i) = \sqrt{\frac{\text{OverID}(O_i)^2 + \text{UnderID}(O_i)^2}{2}} \quad (4)$$

In this regard, a total error equal to zero indicates a complete match between the manual crown digitizing (Reference data) and the tree crown area extracted from the methods.

3. Results and Discussion

Figure 5 shows the location of some pine trees recorded in the study area. Torres et al. (2018) studied 325 tree stands in estimating the characteristics of single almond trees on UAV data, which is close to the number of samples in the present study. Also, in previous studies, Hosingholizadeh et al (2023) emphasized the necessity of studying trees with different size of tree crown area to have solid conclusions of the robustness of the method. The location of the trees in Figure 5 shows that they are well spaced and dispersed across the area. The general distribution of trees is from east to west. The distance between trees reduces light competition between them. Also, their placement on slopes facing the sun and away from it can provide a diversity of conditions and tree characteristics to support the statistical analysis.

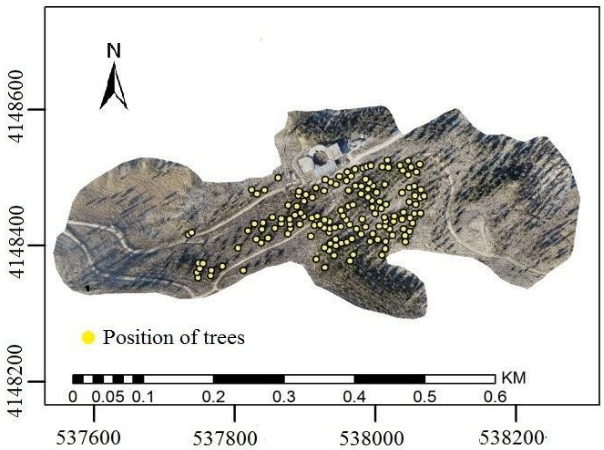

Figure 5. Position of tree on the ground.

In this study, 324 Eldarica pine trees, according to the difference in planting year, were directly measured in the field. As shown in Table 2, the trees in the region have a diverse range of small and large diameters. The small diameters and large diameter are varying from 1 m to 7.8 m, and 2.3 m to 11.6 m respectively. Also, the coefficients of variation of height (38.9), small diameters (25.4), and large diameters (23.4) are relatively high that show the trees in the region are not the same.
On the other hand, the standard deviation numbers in the physical parameters of trees show a good dispersion for all parameters of a tree. In this research the standard deviations for small and large crown diameters in the study area are 1.1 and 1.4, respectively (Table 2). Although, tree height was not used in the calculations, but it alongside the crown diameter parameter gives a better perspective of the pine trees of study area.

Characteristic	MAX	MIN	CV	STD	MEAN
Height (m)	13.1	0.5	38.9	2.6	6.6
Small Diameter (SD) (m)	7.8	1.0	25.4	1.1	4.3
Large Diameter (LD) (m)	11.6	2.3	23.4	1.4	5.8

Table 2. Summary of the field measurements of small and large diameters. maximum value (Max), minimum value (Min), Coefficient Variation (CV), standard deviation (STD).

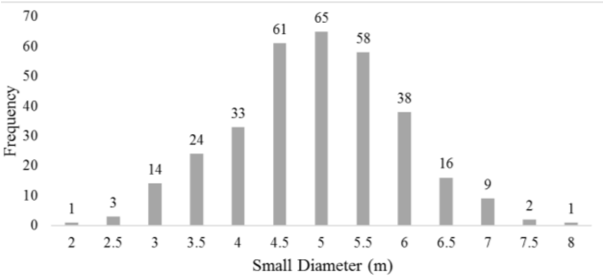

Figure 6. Small crown diameter frequency distribution.

The histogram (Figure 6) shows that size of 86% crown small diameters are between 3.5m and 6m that the most them are between 4.5m to 5m. On the other hand, in large diameters, the numbers are mostly between 4.5 and 7.5 meters (Figure 7). Therefore, it can be concluded that the pine trees are not in the early stages of growth. In fact, the trees have had the opportunity to adapt to the soil, sunlight, and climate, or rather, the microclimate of the region, and this leads to better conclusions based on the data and studies of crown geometry.

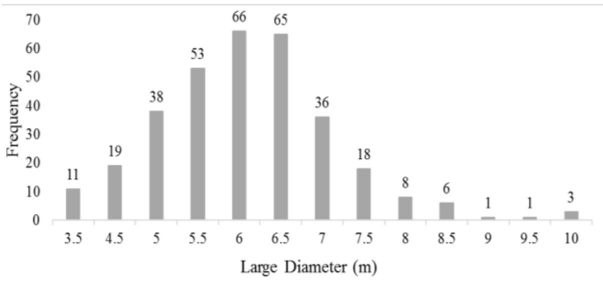

Figure 7. Large crown diameter frequency distribution.

By examining the box plot, it can be seen that more than 50% of the small diameter data have a value above the mean, while the large diameter data have a completely different distribution, that is, more than 50% of the large diameter data are less than the mean. The large diameter data also have a greater range of variation. The horizontal red line shows the average of small diameters (4.3m) and the horizontal green line shows the average of large diameters (5.8 m) (Figure 8).

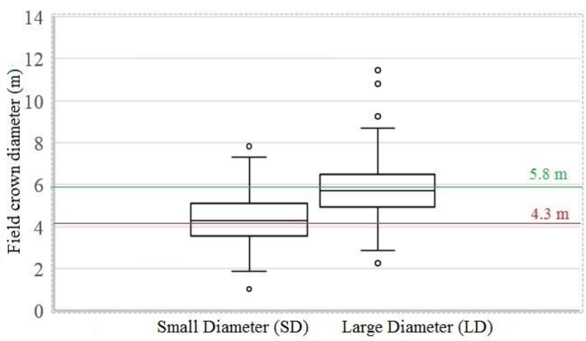

Figure 8. Box plot of small diameter (SD) (Left) and large diameter (LD) (Right) of crown of 324 pines measured in the field.

Figure 9 shows the distribution of the digitized crown area of pine trees. As can be seen, 68% of the tree area is in the range of 11 to 19 square meters, and only 8% of the trees have an area greater than 23 square meters. By comparing the small and large crown diameters with the crown area, it is possible to somewhat understand the coordination of the growth of the different structural components of the tree. Perhaps one of the reasons for this is the lack of light competition among the trees in the study area.

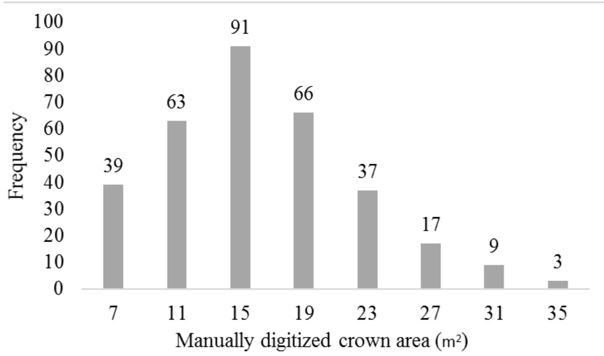

Figure 9. Manual digitizing crown area frequency distribution.

Table 3 evaluates the crown areas of pine trees using the manual digital crown area. This table shows that using Oval gives better results than Circle. Using Oval not only brings the minimum, maximum and average parameters closer to the manual digital results, but also provides a better estimate of the accuracy (RRMSE=0.29, R^2=0.84, overID=0.18, underID= 0.23).
On the other hand, the estimation using the circular geometry with small and large crown diameters ranked next with RRMSE=0.52 and R2=0.42 and RRMSE=0.59, R2=0.37, OverID=0.0.46 and UnderId=0.22. One of the reasons for the small and large diameter circles being in the third and fourth rows is the inclusion of empty spaces as crowns.

Crown area methods	Min	Max	Mean	SD	CV (%)
MD	0.63	45.64	17.55	8.11	46.21
OBD	0.83	51.21	16.9	6.70	39.64
CMD	0.61	54.57	18.21	7.65	42.00
CLD	1.42	72.48	21.25	12.37	58.21
CSD	0.51	37.19	14.55	9.13	62.74

Table 3. Tree crown area estimation by using different method.

By observing the box plot, it can be seen that more than 50% of the results with the CLD and CSD methods were estimated below the average, while more than 50% of the responses with the CMD and OBD methods were estimated above the average. Based on these results, the average area data obtained from the digitization of tree crowns was 16.22 square meters (Figure 10).

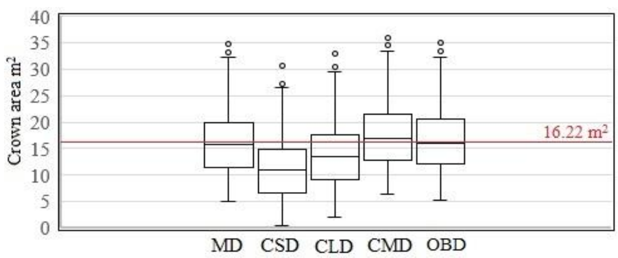

Figure 10. Comparison of crown area of pines based on different geometric shapes of crown (Circular with small diameter CSD, Circular with large diameter CLD, Circular with mean diameter CMD, Oval with both diameters OBD) with manual digitizing (MD) as reference data. The red line shows mean crown area based on MD.

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Figure 11. Different tree crown geometries shape.

4. Conclusion

The influence of environmental factors, especially climate and soil, affects the shape of the tree crown surface, making the estimation of tree crown area challenging. As a result, this study demonstrates the performance of different geometric methods for estimating crown area from high-resolution images. All geometric methods estimated different crown areas. However, their accuracy when applied to trees shows that it is crucial to consider the correct base geometry. Also, this study emphasizes the importance of comparing crown shape in addition to crown area. While field measurements based on oval shapes provided crown area estimates almost identical to those obtained through manual digitization, other field methods did not accurately estimate the irregular and often asymmetrical shapes of real pine crowns. Future studies should explore more complex shape descriptors and examine a wider variety of tree species to improve the generalizability and accuracy of crown area estimation methods across different forest types and conditions. These results provide valuable insights for managers and planners to facilitate forest monitoring that supports management policies in the forest sector.

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