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Digital Image Processing based Methodology for Accurate Estimation of Leaf Length, Width and Aspect Ratio

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ABSTRACT

This paper suggests a method for estimating the length and width of plant leaves that is based on image analysis. Accurate measurements of leaf dimensions, including length, width, and aspect ratio, are essential for physiological research, crop development initiatives, and plant phenotyping. A flatbed scanner is used to capture the image, which is then saved in TIFF format and converted to binary. The image is then thresholded. Following thresholding, a bounding box was created, and the leaf's length, breadth, and aspect ratio were approximated using it. In addition to being labour-intensive and time-consuming, traditional manual measures are also prone to human mistake. For calculating leaf linear parameters, image processing techniques offer a quick, automated, and accurate substitute. This study offers a reliable approach for utilising image processing techniques to estimate the length, width, and aspect ratio of leaves. Image acquisition, pre-processing, rotation, segmentation, feature extraction, and dimensional analysis are all included in the suggested method. The coefficient of determination (R2) and root mean square error (RMSE) were analysed to assess the experimental outcomes. Leaf length, width, and aspect ratio have maximum RMSEs of 0.565, 0.275, and 0.195, respectively. In a similar manner, R2 values of 0.980, 0.955, and 0.981 are determined for leaf length, width, and aspect ratio, respectively. The suggested methodology's ability to determine the length, width, and aspect ratio of such leaves with a high degree of accuracy is demonstrated by the low RMSE and high R2. The methodology's correctness and efficiency are demonstrated by experimental results, which make it a useful instrument for plant sciences and agronomy.

Keywords: Leaf dimensions, Image processing, Length estimation, Width estimation, Aspect ratio, methodology, segmentation.

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INTRODUCTION

Because it affects radiation interception, water and energy exchange processes, and crop growth and production, a plant leaf's surface area is an important metric (Mack et al., 2017). Therefore, a number of studies have sought to quantify leaf areas exactly, which have historically been calculated quantitatively using both direct and indirect methods (Bre´da, 2003). Destructive plant sampling is a component of direct approaches, such as blueprinting, leaf area metering, and scanning. Therefore, it is not possible to measure the same leaf more than once. Furthermore, it takes a lot of work to measure the leaf area directly (Liuet al., 2017).The application of a regression model between the leaf's area and one or more of its dimensions (length and/or width) is an alternate non-destructive and indirect method that allows for the repeated sampling of the same leaves and is reasonably priced (Yeshitila and Taye, 2016; Cristoforiet al., 2007).

Leaf dimensions must be measured in order to comprehend plant productivity, growth, and health. The longest distance between the centroid and the two leaf margin ends on opposing sides of the centroid is known as the leaf length. The distance between the leaf's opposite side on the margin and the point where it intersects the centroid is known as the leaf width. Applications of image processing in plant phenotyping have been the subject of numerous studies. Du et al. (2019), for instance, showed how convolution neural networks (CNNs) may be used for leaf segmentation. Likewise, Apte and Jadhav (2020) created algorithms for agricultural crop size and form analysis.

Despite these advancements, it is still challenging to precisely quantify leaf measurements due to variations in leaf

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morphology, overlapping, and image noise. Our study extends the existing framework by providing a comprehensive and adaptable method for leaf dimension estimation that addresses common problems in image-based measurements.One of the most rigorously specified techniques for accurate and dependable picture detection is the Canny Edge Detection Algorithm. To acquire the best results from the matching process, it is essential to identify the real edges, which is a basic step in image processing. Selecting edge detectors that are most appropriate for the application is crucial because of this. In this case, we selected a clever edge detector. The optimal edge detector is another name for the Canny edge detection technique (Gonzalez and Woods, 2018). The image is initially smoothed by the astute edge detector to remove any noise. After that, it determines the gradient of the image to emphasise areas with high spatial derivatives (Ananthiet al., 2014).The inefficiency and human error potential of traditional manual measurement techniques are their main drawbacks. Leaf parameters are essential for phenotypic characterisation and ecological research, and new developments in image processing provide automated and precise substitutes.

This study offers a technique for very accurate leaf length, width, and aspect ratio estimation that makes use of image processing. We go over the computational methods used, assess the suggested method's performance, and contrast it with manual measurement procedures.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in a mango orchard located in Rehmankhera, Lucknow, Uttar Pradesh, India (latitude,80º 30' to 80º 55' E ;longitude, 26º 45' to 27º. 10' N ; altitude, 123 m). The place has sub humid Subtropical climate. The annual mean temperature is 12.4˚C, and the annual mean rainfallis 592 mm. The average Temperature is around 25°C and average annual rainfall is 726 mm.

Data collection

The Central Institute for Subtropical Horticulture, or ICAR, is a research facility in Rehmankhera, Lucknow, Uttar Pradesh State, where this study was carried out. A variety of plant species' healthy leaves were gathered. Mango (M), guava (G), Jamun (J), and custard apple (CA) leaves of various sizes were gathered

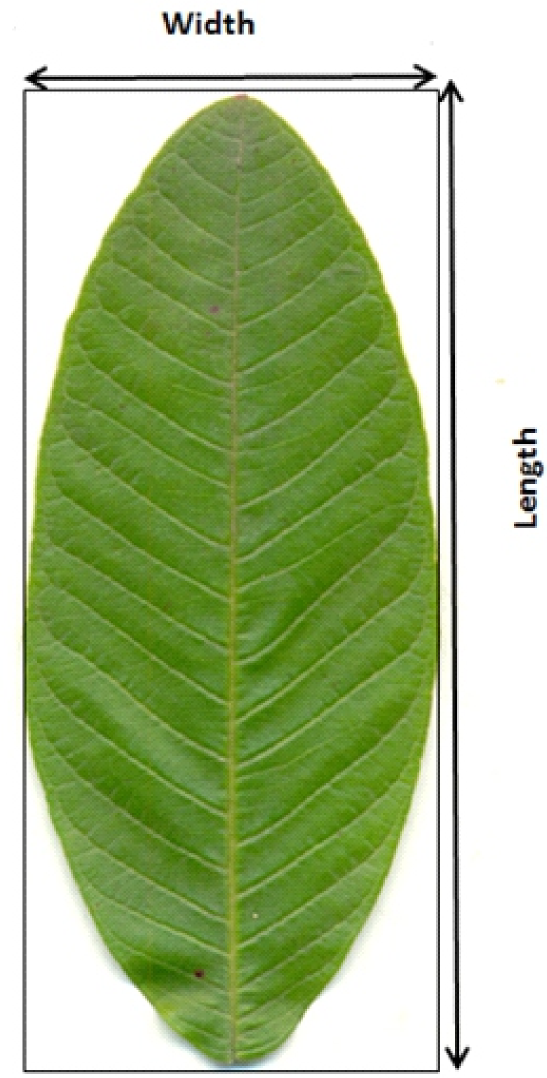


Fig.1: Colour leaf of guava with length and width

Random samples of fully expanded leaves of varying sizes were taken for each cultivar. After being carefully separated and put in paper bags, the fresh leaves were brought straight to the lab to be scanned at 300 dpi in TIFF format using a flatbed scanner to create a digital image. We manually measured the leaves' length and width in this investigation using a measuring scale.

The following proposed methodology was used to perform measurements based on image processing using MATLAB version R2015a (MathWorks, Inc., Natick, USA):

PROPOSED METHODOLOGY

Figure 2, shows the flowchart of the algorithm involved in the leaf length, width and aspect ratio measurement. Images of the plant leaf are acquired using scanner. Every image is kept in high resolution i.e. 300 dpi and TIFF format. After that, choose various images and determine the leaf linear parameters.

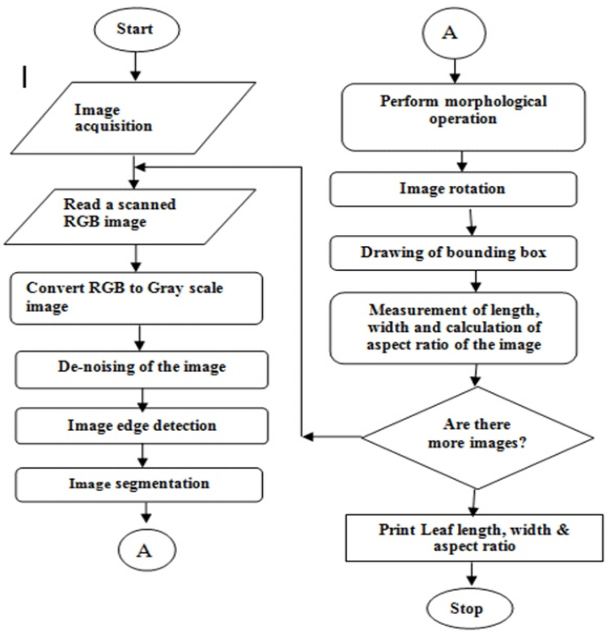


Fig. 2: Flowchart of the steps involved in the leaf length, width and aspect ratio measurement

The following describes the specifics of each phase used in the technique development and displayed in the flow chart:

Image Acquisition

A flatbed scanner was used to take high-resolution coloured pictures of healthy leaves. The leaves were arranged flat on a contrasting background to maintain uniformity (Fig.3)

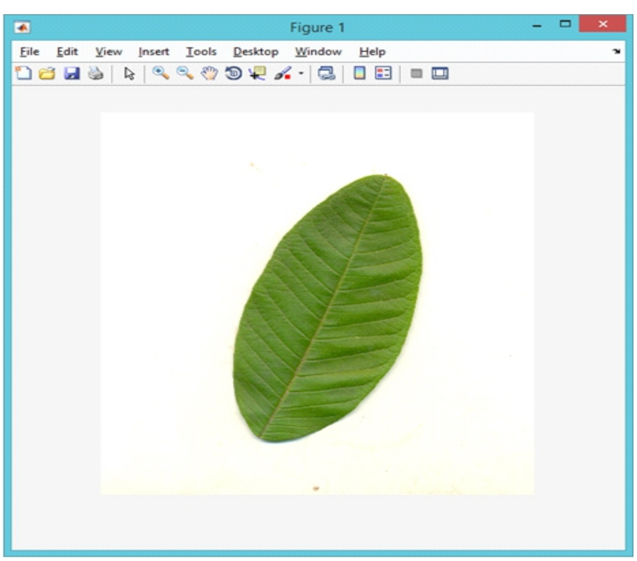


Fig. 3: Coloured and tilted guava leaf

Pre-processing

Gray-Scale Conversion:

Images were converted to grayscale to reduce computational complexity (Fig.4).

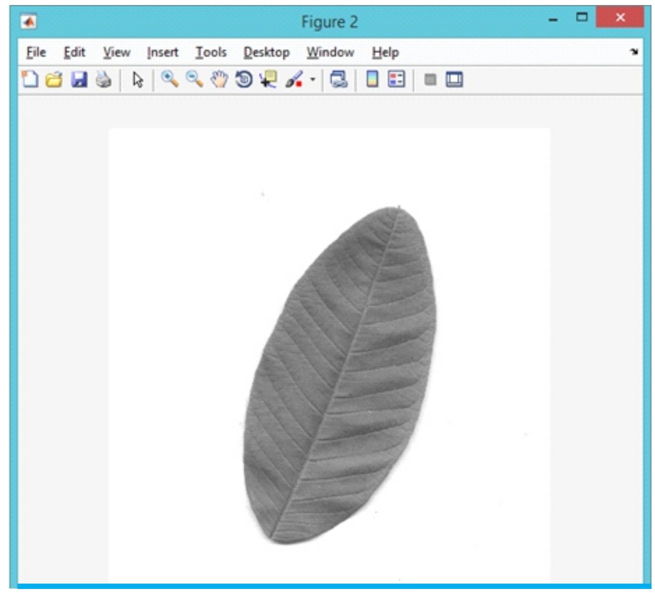


Fig. 4: RGB to Gray scale converted leaf

Noise Reduction

Median filtering was employed to remove noise while preserving edges.

Contrast Enhancement

Histogram equalization was used to improve image contrast.

Segmentation

The leaf region was extracted using adaptive thresholding and morphological operations (Fig.5).

Thresholding

Otsu's method was applied to binarize the image (Otsu, 1979).

Morphological Operations

Techniques such as dilation and erosion were used to refine the binary mask and eliminate artifactsrefining the binary image using morphological operations like dilation and erosion (Smith and Jones, 2017).

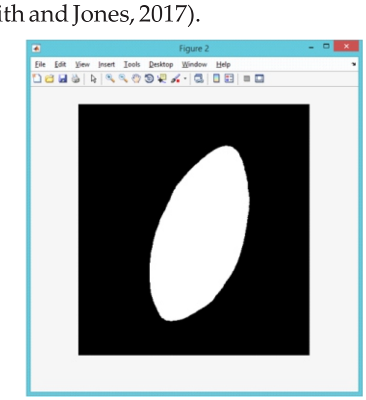


Fig.5: Image segmentation through thresholding and morphological operations

Image Rotation

- ❖ Determining the angle of image inclination, if any.
- ❖ Rotating the image to make exact in vertical position i.e. parallel to Y-axis (Fig.6).

Drawing of bounding box

- ❖ A rectangular bounding box was drawn with closely surrounding the leaf border (Fig.6).

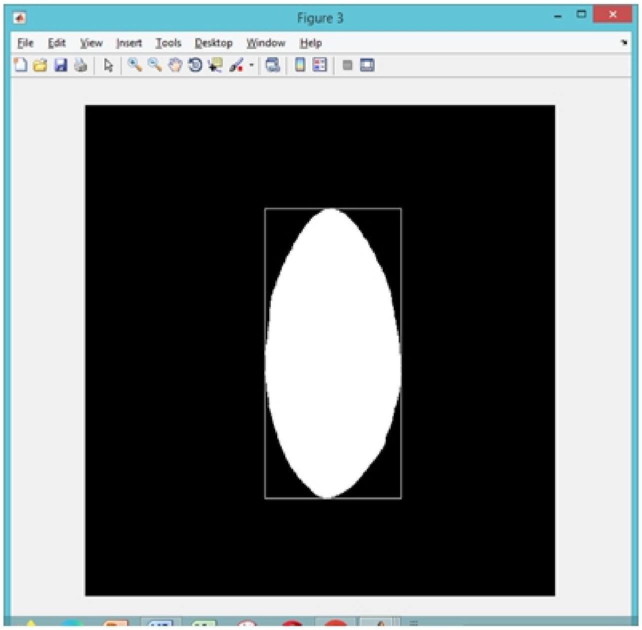


Fig. 6: Tilted leaf image rotated to perpendicular position with rectangular bounding box.

Feature Extraction

- ❖ Measuring the major axis of fitted rectangle was calculated as leaf length.
- ❖ Measuring the minor axis (of fitted rectangle was calculated as leaf width.
- ❖ Calculating aspect ratio (Length/Width).

Dimensional Analysis

The extracted parameters were validated against ground truth measurements obtained through manual measuring scale/ calliper-based methods.

RESULTS AND DISCUSSION

Dataset

A dataset of 40 leaf images from diverse plant species was used to evaluate the methodology. For validation, 45 leaves of different shapes comprising mango (M), guava (G), Jamun (J), Custard apple (CA) were collected from ICAR-CISH research farm, Rehmankhera. Some of leaf images shown in Fig. 7.

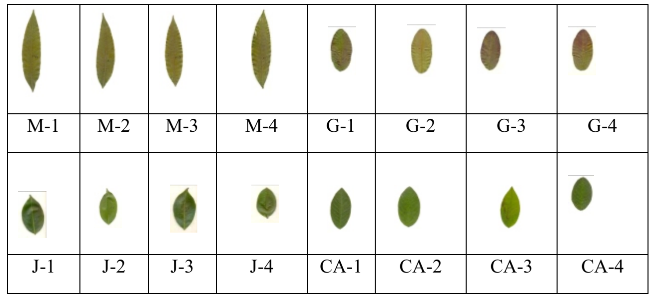


Fig. 7: Sample leaves used for software validation (image size is reduced)

The leaf length and width were measured manually using measuring scale, which is mentioned as measure leaf Length, Measured leaf width and aspect ratio. Thereafter, images were scanned on HP 3200C flatbed scanner. Leaf images scanned at 300 dpi resolution and as tiff format.
Hence, all 40 images were scanned as tif image and at 300. The proposed methodology is implemented using Matlab programming language for above leaves images and leaf Length, Width and Aspect ratio were calculated and accuracy results are shown in Table 1.

Performance Metrics

The accuracy of the measurements was assessed using root mean square error (RMSE) and coefficient of determination(R 2). The methodology achieved RMSE of 0.565cm, 0.275 cm and 0.195, for leaf length, width and aspect ratio, respectively. Similarly, R2 was found to be 0.980, 0.955, and 0.981 for leaf length, width, and aspect ratio using the methodology which is demonstrating high precision.

Comparative Analysis

The proposed method outperformed manual measurements in terms of speed and consistency. It also showed robustness against variations in leaf shape, orientation, and size.

Validation

For validation of proposed methodology, statistical analysis has been performed to assess the accuracy between manually measured leaf parameters and same parametersestimated using the proposed methodology. The details are given below:

Accuracy Assessment

For assessing the accuracies between measured and calculated results by using prescribed method ,the following accuracy measures have been considered:

Root Mean Square Error (RMSE): Root Mean Square Error (RMSE) is a common way to measure how well a model predicts quantitative data.
It is calculated by 'Eq.(2)'

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \qquad (1)$$

Coefficient of determination (R2): It provides the proportion of the variance in the dependent variable that is predicted from the independent variable.The value of coefficient of determination (R2) varies 0 to 1 .Coefficient of determination (R2) is popular statistical measure that represents the proportion of the variance for a dependent variable. It explained an independent variable or variables in a regression model. Formula for calculation of Coefficient of determination is shown in 'Eq.(2)

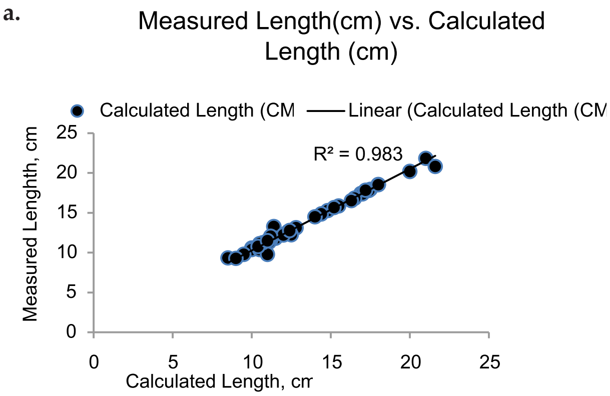
$$R^2 = \frac{\left[\sum_{i=1}^{N}(x_i-\bar{x}_i)(y_i-\bar{y}_i)\right]^2}{\sum_{i=1}^{N}(x_i-\bar{x}_i)^2\sum_{i=1}^{N}(y_i-\bar{y}_i)^2} \quad (2)$$

Where xi and yi are the measured and calculated leaf area for the ith evaluation, respectively, and n is the number of samples.

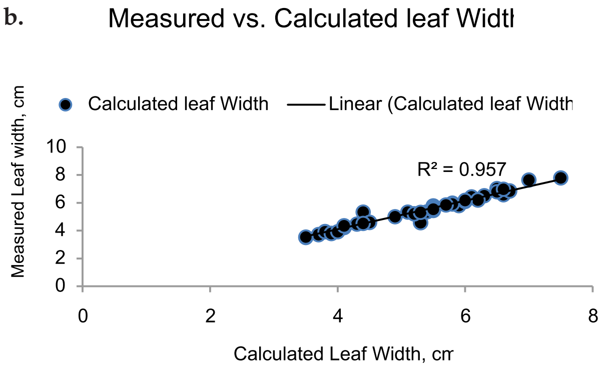
Where xIand yiare the measured and calculated leaf length/width/aspect ratio and N is total number of leaf samples.Scatter Plots have been made between different measured and c parameters estimated/ calculated by proposed methodology (Fig8(a-c))

Scatter Plots between different measured and calculated parameters

a.



b.



c.

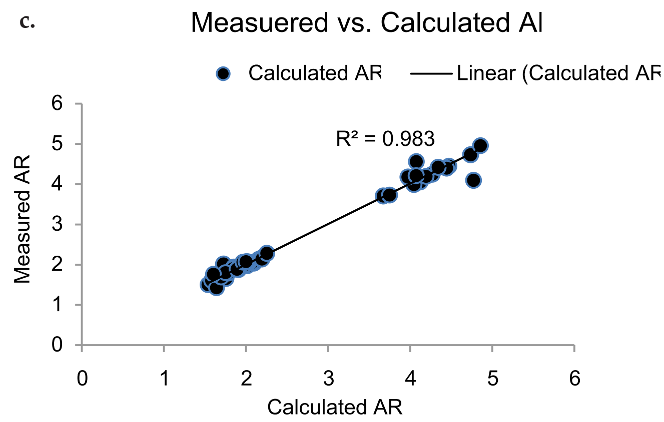


Fig. 8: Scatter chart between (a)measured leaf length vs. calculated length(b) measured leaf width vs. calculated width (c) measured leaf AR vs. calculated AR

Table1: Summary of different accuracy measures

	Leaf length(cm)	Leaf Width(cm)	Leaf aspect ratio
RMSE	0.565	0.275	0.195
R^2	0.980	0.955	0.981

From results of Table.1, it is observed that R2 is quite high and RMSE is quite low for leaf length, width and aspect ratio measured by digital image processing method.
Hence, it is concluded that the methodology based on digital image processing calculates all three leaf parameters with good accuracy; therefore, it is a reliable method to measure these threeleaf parameters quickly with higher accuracy.

DISCUSSION

Strengths

The proposed methodology offers high accuracy, adaptability to diverse leaf morphologies, and significant time savings compared to manual approaches.

Limitations

The accuracy of the methodology is influenced by image quality and background contrast. Leaves with intricate serrations or overlapping structures may pose challenges for segmentation and feature extraction.

Future Work

Future research will focus on development of user friendly software for fast, accurate and automatic estimation of leaf length, width and aspect ratio based on this methodology.

CONCLUSION

This study presents a reliable and efficient image processing-based methodology for accurate measuring of leaf length, width, and aspect ratio. The results demonstrate its potential for widespread application in plant phenotyping and agricultural research. By automating leaf measurements, this approach addresses the limitations of traditional methods and paves the way for more accurate and scalable plant studies.

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