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Comparison between machine vision and manual leaf area estimation approaches for the precision horticulture management

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Abstract

Easy, accurate, and economical method for determining the individual leaf area of the plants is a useful tool in agronomic and physiological studies. To increase agricultural yield and production with minimum cost, farmers are adopting different modern and precision farming techniques in traditional agriculture. In this study, three different leaf area measuring methods (A1= image processing method, A2= leaf area meter, and A3= graphical method) were compared by selecting sixty leaves (with different shapes and sizes) of six different plant species. In addition, A1 and A2 were performed by using Photoshop CS6 software and a laser leaf area meter (CI-203) respectively, and simple graph paper was used for A3. The experimental results indicated that the value of adjusted R^2 0.9988 was obtained with a relationship between the A1 and A2 methods. However, the value of adjusted R^2 0.9992 was obtained for the relationship between A1 and A3 methods. Therefore, this study concluded that the A1 method obtained sufficient accuracy in contrast to A2 and A3 methods for the leaf area measurement. The important characteristics of the A1 method are its rapidness, easiness, and suitability for precise and cost-efficient estimates. Thus, the A1 method can be used to measure the leaf area of any plant in many different experiments without using expensive equipments.

Keywords: Non-destructive; Image processing; Leaf area; Digital images

1. INTRODUCTION

Day by day, the world population is growing, thus it is necessary to increase agricultural production for feeding the hunger world population in the near future. Besides, agriculture plays an important role in the development of the world economy and can significantly affect the living standard of the people (Syed et al., 2019; Lakhiar

et al., 2020; Lakhiar et al., 2018; Lakhiar et al., 2018; Tunio et al., 2020). In agriculture, a healthy plant is considered an essential factor for significant yield. Studies reported that healthy plant growth is highly dependent on the different characteristics (leaf area, number of leaves, stem width, and total plant height) of the plant (Mohsenin, 1986). In this regard, the leaf area of the plant is an important parameter for significant growth. Therefore, its measurements and estimations are an important factor for the management, forecasting production, storage, and selling of various leaf-based plants (Lizaso et al., 2003). Besides, several researchers are considering leaf area as an important parameter for their research studies. Studies reported that accurate leaf area measurement is an important factor for understanding the modeling of the ecosystem etc.

In the literature, there are several methods are reported for measuring the leaf area of the plants. Generally, leaf area measurements or estimations are conducted by using different types of non-destructive and destructive methods. However, traditionally, it is measured by using the grid count method, regression equation, gravimetric method, photoelectric scanning, and planimeter method. A study by Linda et al., (1990) reported that in the gird count method, the leaf of the selected plant is detached and placed on a piece of grid paper. After that, the plant leaves are placed on the grid paper, and outlines are drawn with the help of a pencil. This study further reported that the method is simple and has high accuracy. But it is laborious and time-consuming when applied on large scale. Furthermore, another researcher Montgomery, (1911) stated that with the regression method, an equation $A = b \times w \times l$ is used for leaf area measurement. In the above equation, the b is the leaf shape coefficient, w is the width of the leaf and l is the length of the leaf. This method is non-destructive, but the main problem is that it requires the usage of many different equations for different plants. Because the value of the coefficient of b is different among the different plant species. In addition, in the gravimetric method, firstly, a leaf of the plant is removed from the plant and carefully placed on the white paper. Secondly, the shape of the leaf is traced on the white paper and the traced portion is cut out from the paper, accordingly. After that, the weight of the cut paper piece traced with the leaf area is compared with the known area on the same paper (Ross & Ross, 1995). This method is easy to perform but it is laborious and takes extra time. Also, it is not suitable for large-scale measurements. Another method used for leaf area measurements is performed through digital estimation of intercepted light passing through a light beam with the aid of constant-speed conveyor belts such as a leaf area meter. Compared to the above methods, this method is highly accurate, reliable, and convenient for measuring and estimating the leaf area of the plants by using mechanical portable scanners, but repetitions of readings are essential (Daughtry, 1990). Linda et al., (1990) & Montgomery, (1911) reported that the planimeter offers a less time-consuming technique, but its accuracy is limited, especially for relatively small leaves.

According to the literature review, the world horticulture sector is significantly improving by adopting several modern techniques and tools. Besides, several researchers concluded that the development of different computer-based image processing techniques in the horticulture sector has become a feasible tool for various plant-based research studies. At present, image processing technology is commonly used for performing work in different fields such as industry, geology, security, medicine, and others. Moreover, for the horticulture sector, such techniques are used for detecting the fruit color analyses, monitoring of plants, fruits, root development, leaf

area measurements, and weed control practices (Chaohui et al., 2010; Hassan et al., 2010; Tan & Abdel, 2010; Sanjay & Shrikant, 2011). Besides, Mayer and Davidson (1987) used a stereoscopic system and identified three-dimensional coordinates of the edge points of the leaf by using the user-interactive program. Another study by Andersen & Kirk, (2005) adopted a stereo vision to estimate the leaf area using images for getting the geometric properties of 10 young plants with 5 to 6 leaves. In addition, Ushada, Murase, & Fukuda, (2007) presented a method that was based on neural networks for monitoring the canopy parameters such as leaf area index. Nyakwende, Paul & Atherton, (1997) measured the leaf area by practicing the regression of the project leaf area from three viewpoints (from the side, top and oblique angle). Tian & Wang, (2009) proposed a method for leaf area measurement of cucumber plants by using the image processing method. In this study, they used reference object and picture pixel number statistics and found a coefficient of variation value of 3.99. Another research team by Enrique, & Enrique, (2009) introduced two new methods for estimating the leaf area by using digital photographs and their reported accuracy was 99%. However, Igathinathane et al., (2006); Chien & Lin, (2000); Chien & Lin, (2000) also measured the leaf area using an image analysis method through computer-aided software. Even in the above-described methods such as using digital cameras and calculating the leaf area by computer programs, taking photos very fast and accurate analysis although this process takes a long time and often equipments are very expensive (Bignami and Rossini 1996; Lu et al., 2004).

Thus, this work aimed to compare the accuracy among the different leaf area measuring techniques and recommended an alternative leaf area estimation method. Which should be accurate, quick, easy, and certainly cost-effective Furthermore, this paper is organized as; Section 2 discusses the material and methods while Sections 3 and 4 represent the results and conclusions of the study.

2. MATERIALS AND METHODS

2.1 Experiment setup

This study was conducted at the College of Engineering, Nanjing Agricultural University. Furthermore, full-mature leaves of different varieties including pepper, bitter guard, lettuce, eggplant, tomato, and ridge gourd were selected as the plant material. Three different leaf area measuring methods (A1= image processing, A2= leaf area measuring meter, and A3= graphical method) were adopted to complete the study object. In addition, the leaf area measuring systems have consisted of a digital camera, pc, graph paper, 1-yuan coin (reference object), white paper sheet, leaf area meter, and Photoshop CS6 software for image processing. The experiment was carried out on sixty leaves (with different shapes and sizes) of six different plant species. However, Fig. 1 shows the study selected leaves.

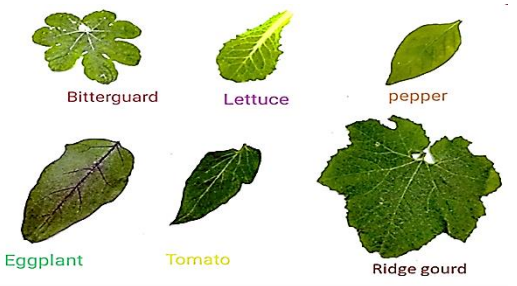


Figure 1 Selected leaves of different plant species

2.2. Graphical method

Generally, leaves differ in shape, size, edge pattern, and organization on the stem. Therefore, to measure the leaf area with a graphical method, the leaves of the selected individual plants were placed on graph paper and the sketches of the plant leaves were drawn and outlined with a sharp edge pencil accurately and carefully. However, the size of each grid was 1mm unit. After that, the total number of grids covered by the outlined edge of the individual leaf was calculated and covered lines were considered as the actual leaf area. It was considered that if the edge outline engaged more than 50% grids of graph paper it would be counted as one, otherwise zero.

2.3 Laser leaf area meter

For the present study, the handheld laser leaf area meter (CI-203) was used. The selected meter was consisting of many sub-systems and was controlled by a microcomputer system which allows for making measurements accurately, easily, and quickly (Bio Sciences, 2016). The measuring process of the meter was first, opening the meter by clicking the on button. Secondly, open the measuring arm until it is extended completely, and then allow it to close slowly upon the leaf to be measured. As the measurement process began the motor started spinning up to speed as soon as the arm opened and the "spinning up", "Stabilizing", and "Arms Open" were displayed in quick sequence, and then "Measurement" near the top line. The "Display" read "Measuring" when the arm closed and the laser power was on. At this point, the leaf was measured through the instrument. When the process was completed, the instrument stopped automatically and displayed the results, respectively. After that, for saving the measurement, the SAVE button was pressed, which was confirmed by showing the near top line of the display. Finally, the whole collected data were transferred to a computer by connecting the instrument to the USB cable. However, Fig. 2 shows the instrument displaying measured data.

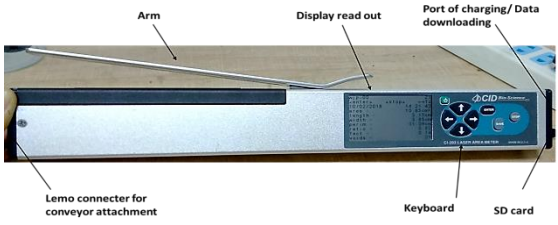


Figure 2 CI-203 Laser Leaf Area Meter

2.3 Leaf area based on image processing

Adobe Photoshop CS6 is the world's best image processing software. The following steps were involved in the measurement of the leaf area.

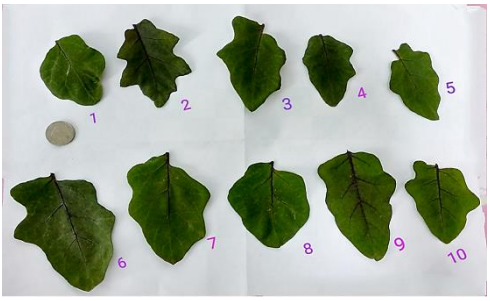
2.3.1 Image acquisition

Firstly, the leaves of the selected plants with a 1-yuan coin as a reference object were placed on a white background (white sheet) and images of the leaves were captured. Besides, the camera was positioned horizontally to the plane of the leaves subsequently. The acquired images were transferred from the camera to the computer. In addition, the distance between the camera and vegetation was neither too close nor too far. It was adjusted in such a way that the photograph was conveying proper data, as shown in Fig. 3.

Figure 3 Acquisition Image of the lettuce leaves with a reference object.

2.3.2 Image processing

Adobe Photoshop CS6 software was used to execute the operations of image processing. The threshold range was set to convert the RGB image into a binary image. After that, the estimated leaf was segmented from the surroundings and the number of pixels covered by the leaf were counted. Also, the magic wand tool was used, which allows us to measure different color fluctuation images, especially where the edges are not uniformly shaped. To calculate the pixel values, the selection was made in Photoshop and the "refresh" button was clicked from the relevant menu of the histogram. Finally, the number of pixels of the selected image was determined, as shown in Fig. 4.



(a)

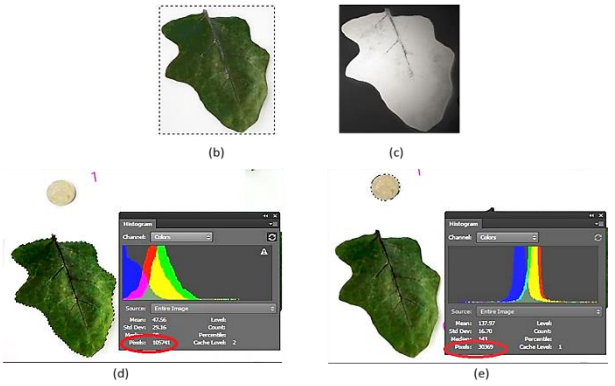


Figure 4 Processing steps of an acquired image (a-e).
(a) selected samples of Eggplant leaves with 1-yuan coin (reference object), (b-c) conversion of RGB image into a binary image, (d) specified selected leaf area into pixel value, (e) specified selected leaf area into pixel value of the reference object

2.3.3 Determination of the area

After converting the scanning data into pixel values, the leaf area was determined by using the following equations (1-3).

In this study, a 1-yuan coin was chosen as a reference object whose area was determined by using equations 1 and 2:

$$AC = \pi r^2 \quad (1) \text{ or}$$

$$AC = \pi(d/2)^2 \quad (2)$$

Where AC was coin area (cm^2) and d was the diameter of the coin

$$ILA = \frac{AC * LP}{CP} \quad (3)$$

Where ILA is leaf area based on image processing (cm^2)
AC was the leaf pixel number and CP was the coin pixel number

2.4 Data Analysis

Relationships between (a) graphical method and image processing method (b) leaf area meter and image processing method were related according to y = a + bx, where x is the independent variable (leaf area estimated by leaf area meter or graphical method) and y is the dependent variable which is estimated by image processing method. Also, the regression equation was calculated between each relationship by using SPSS.

3. RESULTS AND DISCUSSIONS

To test the performance of the selected measuring systems, sixty leaves of six different plant species were selected for leaf area estimation. In addition, the regression analysis results reporting the relationship between the leaf area measured by the image analysis method (A1), and the graphical method (A3) is given in Table 1. In Table 1, the results showed that the two sets of estimates were strongly related to each other for all the selected species. However, the data showed that the image processing method measurements achieved a high level of accuracy with graphical method measurements (Fig. 5).

Table 1 Regression analysis between leaf area measured by the image analysis method (y) and graphical method (x).

S. No.	Leaf species	Regression equation	R^2
1	Tomato	y = 1.0556x - 1.3594	0.98
2	Eggplant	y = 0.9982x - 0.0536	0.99
3	Bitter guard	y = 1.0631x - 1.895	0.99
4	Ridge gourd	y = 1.0003x + 0.025	0.99
5	Pepper	y = 1.0578x - 1.2113	0.98 0.99
6	Lettuce	y = 1.0019x + 0.2156	

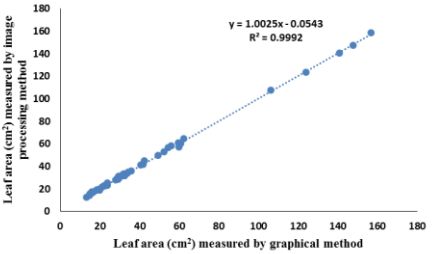


Fig. 5. Correlation analysis between image processing method and graphical method

Besides, Table 2 represents the leaf area computed results from the images processed by the A1 and A2 methods. Whereas all the six species represented good-adjusted R^2, with a little deviation observed in respect to the tomato leaves. However, almost all species appeared to be of linear and significant ($R^2 = 0.9715\ to\ 0.9997$) value.

Table 2 Regression analysis between image analysis method (y) and leaf area meter (x).

S. No.	Leaf species	Regression equation	R^2
1	Tomato	y = 1.0742x - 2.258	0.97
2	Eggplant	y = 1.0184x - 0.4107	0.99
3	Bitter guard	y = 1.0253x - 0.9064	0.99
4	Ridge gourd	y = 1x - 0.1412	0.99
5	Pepper	y = 1.0101x - 0.3606	0.99 0.98
6	Lettuce	y = 1.0499x - 1.0292	

Afterwards the correlation between leaf area meter and image processing of the sixty leaf images were calculated. As shown in fig. 6, the two methods produced a very high correlation of $R^2 = 0.9988$.

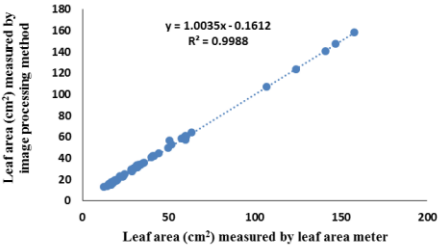


Fig. 6. Correlation between image processing method and leaf area meter (CI-203).

The correlation analysis result between A1 and A3 methods showed the obtained R^2 value (0.9992) (Fig. 1), however, similar results were reported by Pandey & Hema, 2011. They used the millimeter graph paper with commercial equipment (0.933- 0.998) and predicted the leaf area of different species. Moreover, Cristofori et al., 2007 reported that the leaf parameters such as length, width, shape, size, and combinations have been used for leaf area estimation through the accuracy of the predictions which is dependent on the variation of the leaf shape due to differential genotype (Lobet, Draye & Erilleux, 2013). Bakr, 2005 reported the comparison of manually and the software measured results and said that there was no significant difference. Bylesj¨ o et al., 2008 highlighted that software provides a high level of accurate results in large datasets in an automated or semi-automated work flow.

In this study, the relationships between the image processing method (A1) and the graphical method (A3) represented a better correlation compared to the relationship between image processing and leaf area meter measured data set. However, measuring leaf area by leaf area meter is time-consuming, expensive equipment cost and a fastidious approach, which explains the potential of that method in the analyzes of leaf area. However, the leaf area measuring with the A1 method is simple, rapid and reliable. Also, it doesn't need any mathematical modelling for the determination of the leaf area. The advantage of this study is demanding low-cost equipment as its requirement of only a computer as a material to implement the prediction using the model makes the protocol proposed here an accessible tool to researchers and farmers which can be applied to attached leaves (non-destructive) anywhere, in forest or agricultural field.

4. CONCLUSIONS

Leaf area measurement is an important issue in monitoring plant growth and development. The image processing methods described in this paper were used to measure the leaf area of six plant species. Experiments were performed to test the performance of the estimating method by comparing A1, A2 and A3 methods. The study results displayed that the A1 method had a more significant linear relationship with the estimated obtained A3 method. Moreover, the A2 and A3 methods are generally used for leaf area measurement, but these methods are time-consuming and laborious when applied on a large scale. However, the A1 method has high accuracy and precision. Even if the leaf with maximum width and length is there it takes less processing time. This method is also feasible to measure leaf area of any type, size or shape with the same accuracy and reliability. Besides, the A1 method can be valuable to detect the presence of holes and changes in leaf color to infer the presence of diseases. It would achieve a better estimate of the leaf area and disease severity for the application of pesticides as well as fertilization.

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