academicJournals

Vol. 12(20), pp. 1702-1712, 18 May, 2017
DOI: 10.5897/AJAR2016.11698
Article Number: D51170464218
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Leaf detector box: Artificial vision system for leaf area identification

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Received 12 September, 2016; Accepted 14 October, 2016

The detection of leaf area in plants is a very important parameter to evaluate growth rates. Nowadays, this analysis is performed manually through a process of counting, cutting and weighing leaf that involves long periods of time, providing subjective results and with low repeatability. The purpose of this research was to develop a computational tool (leaf detector box) to detect leaf area through image processing techniques. The methodology implemented based on application of image processing techniques to segment leaves. Later, morphological operations were apply to eliminate objects that were not part of leaf. Finally, the leaf area was identified through a conversion of pixel to squared centimeter. The validation results showed a determination coefficient greater than 0.97 for four species of plants analyzed with regard to manual analysis by a technical expert. In addition, it validated in a set of 40 leaves precision of algorithm implemented carrying on three measurements for each one at different positions. The results showed a variance of 0.00024 for orange tree leaves, 0.007 for lemon tree leaves, 0.008 for almond tree leaves and 0.001 for mango tree leaves, indicating precision of algorithm providing similar results when it was applied in different opportunities to one leaf. Therefore, the tool becomes a reliable technological support in process of detection leaf area allowing reducing long periods of time and subjectivity in process. Likewise, the repeatability in results were increased.

Key words: Leaf area, growth rates, computational tool, image processing, morphological operations, coefficient of determination.

INTRODUCTION

Currently, various agri-environment processes are developed in different laboratories and institutions worldwide such as Ministry of Agriculture in Colombia (Ministerio de agricultura, 2016), Food and Agriculture Organization (Organización de las Naciones Unidas para la Alimentación y la Agricultura, 2012), Universidad Del Valle (Universidad del Valle, 2016), Universidad Politecnica De Madrid (Universidad Politecnica de Madrid, 2016), among others. One of these processes is study of plant growth by measuring leaf area; this magnitude

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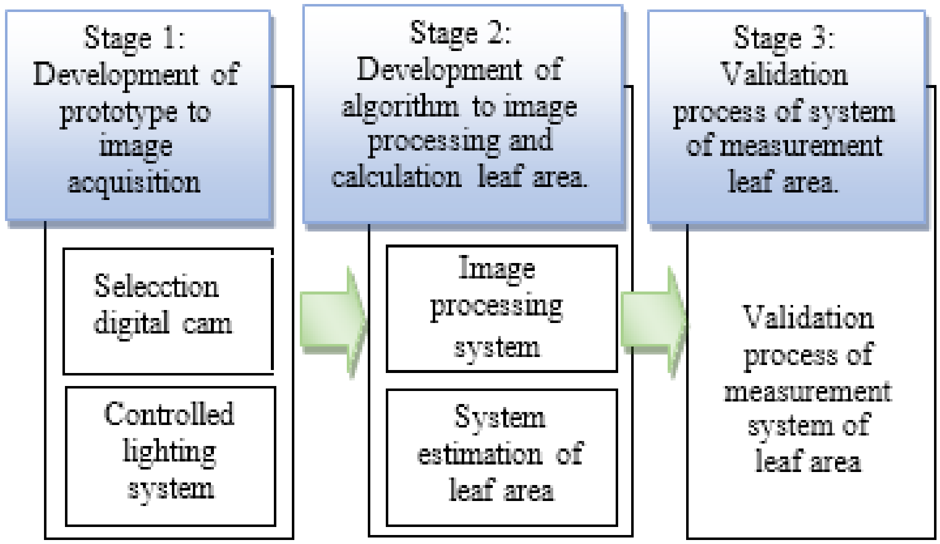

Figure 1. Implemented methodology. Source: Authors.

is one that defines ability to capture the photosynthetically active radiation where the plant makes the development of tissues and nutritional compounds for its own development.

Nowadays, different scientific and technological advances exist to do this measurement. One of them was develop by LI-COR company (Li-cor, 2016), in 2007, they developed a system capable of doing recognition and classification of plants of an automated way using Probabilistic Neural Networks (Gang et al., 2007). In 2009, semiautomatic systems were use making a software CAD (Rico et al., 2009) which used lines of reference to calibration of measurement. Other authors in 2011 used MatLab software (Shivling et al., 2011) to do automatic measurement of leaf area, likewise, there were some algorithms used based on invariants moments (Zalikha et al., 2011) with diverse characteristics that could be used in subsequent analyzes. In 2012, using the software ImageJ (Rincon et al., 2012) the area of semiautomatic way was determined. Also, they developed new advances on using a digital scanner (Mahdi et al., 2012) allowing progress in the detection of the rims of the leaf, due to the big precision of capturing the image with one that counts. Moreover, they developed rapid and precise algorithms in (Piyush et al., 2012), it means the conversion to another color space (CieLab), or through bonding techniques such as Zernike moments and neural networks and radial basis probabilistic (Kulkarni et al., 2013). Finally, in 2014 the segmentation was realized using the component of tone making use of the format HSI (Lin et al., 2014), this segmentation worked with an index of very low error, the last advances in the topic of the measurement of the leaf area were focusing in mobile systems principally in cell phones with operating system android.

However, in Colombia and in case of vegetal physiology laboratories at Universidad de Cundinamarca, an expert measure leaf area manually and result of measurement depends on inspection and visual experience, causing systemic errors during process that affects the reliability and repeatability of results.

The main objective of this research was development of a computational tool that allowed to quantify leaf area, through an artificial vision system based on image processing techniques using the MatLab software.

MATERIALS AND METHODS

In Figure 1, it presents methodology used to develop measurement system of leaf area using artificial vision techniques, which consists of three main stages that are prototype development, processing image algorithms and tool validation.

First, the designs in 3D of prototype for image acquisition were developed, following analyzing of requirements and restrictions of user.

Design of computational tool

To develop project, an artificial vision system was propose, in order to identify leaf area in plants with a maximum size of (30 × 30) cm, with controlled lighting parameters. Then, in Figure 2, show step by step of its construction in Solid Edge.

In the computational tool design, Coll Roger laminas were use, in order to fulfill requirements of user. The system was design with boxy measures of 50 cm wide, 50 cm long and 70 cm high, as is shown in Figures 2A and B. This allowed include image acquisition system (Logitech webcam C270) and lighting system (lED type) inside box to capture images up to (30 × 30) cm. In addition, a support was design to place leaf on an antireflective glass (40 × 40) cm, which helped to prevent contrast variations in image as shown in Figure 2D and C respectively. Additionally, two dampers were

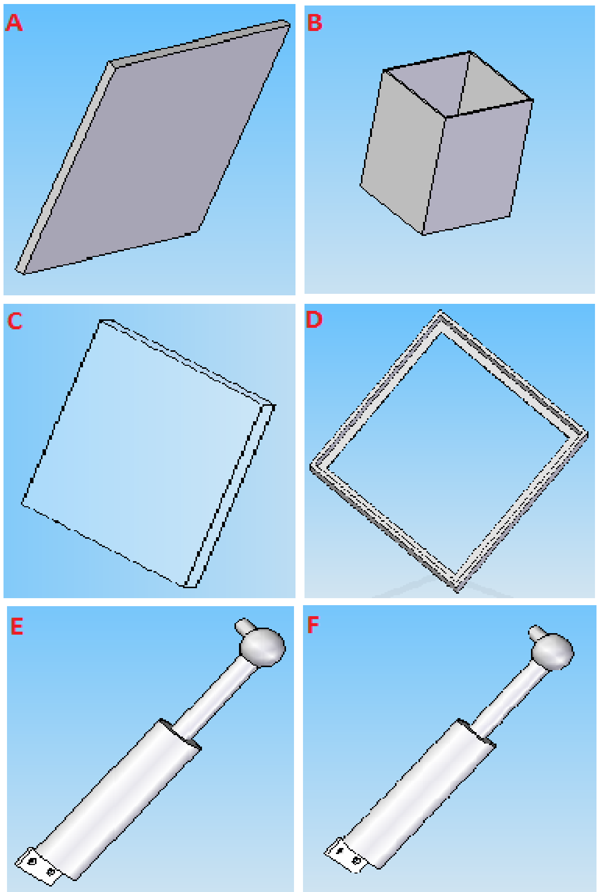

Figure 2. Design in 3D of computational tool. A. front view of lid; B. Side views module; C. diagonal view of glass; D. front view of glass support; E and F. front view damper.Source: Authors.

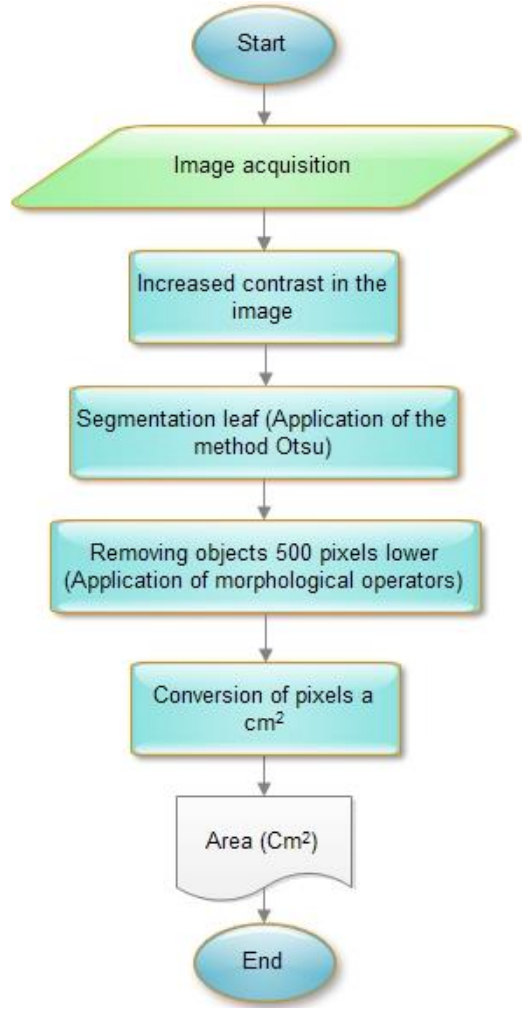

Figure 3. Algorithm for identification of leaf area. Source: Authors.

adapted to the sides of lid to avoid sharp blows as shown in Figure 2E and F. Finally, they were implemented four-rubber foot to give support and stability to tool, allowing displacement in laboratories. Furthermore, it is reprogrammable allowing to be apply to other projects.

Development of algorithm for identification leaf area

The computational tool acquires images by a traditional artificial vision system. The proposed methodology identifies leaf area through application of techniques of image processing. Then, each one described in process stages of in Figure 3.

The first stage consisted in image acquisition process. Then, a contrast adjustment was applied to ease process of segmentation of leaves. Later, Otsu method and morphological operators were use, to segment objects of interest eliminating objects that were not part of leaves. Finally, leaf area was determined through a direct proportion between pixels and image centimeters.

Acquisition and image preprocessing

The stage of image acquisition of tool, was based in a web cam Logitech c270, which obtained images with resolution of (640×480) pixels and relation 4:3 in JPG format, computer equipment presented a processor Amd c60 APU 1Ghz, memory RAM de 2Gb, with an operative system Windows 8.1. Later, edges that limit space were eliminate on images, used to limit size of the leaves. Finally, stage of preprocessing was apply to adjust contrast, allowing decreasing the variance of intensity in pixels.

Extraction of area of the leaves

To extract leaf Otsu method and histogram analysis were implement. This method consisted in comparing values of image in gray scale with a threshold defined by colors that presented object and background of image, was assigned white color to pixels that are above threshold and black color to pixels that are below threshold.

Detection of leaves area

The stage of area detection on leaves was realized by application of Equation 1 through of a factor relation of pixels to cm^2 on image.

Figure 4. Computational tool assembly (leaf detector box). Source: Authors.

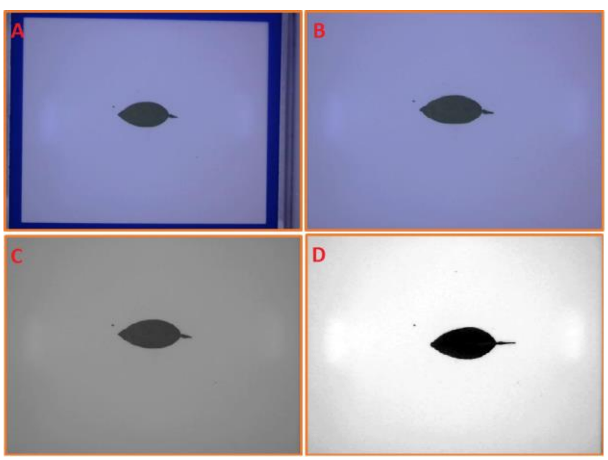

Figure 5. A. Original image. B. Removing of contours, C. Convertion to gray. D. contrast adjustment. Source: Authors.

$$Area(cm^2) = \frac{area\ en\ pixeles * 71{,}355}{12502} \quad (1)$$

Validation of artificial vision system

The validation of computational tool done by a statistical correlation analysis, applying coefficient determination, to evaluate grade of concordance between methodology implemented and conventional methods used. Finally, algorithm precision was determined through a variance analysis of measurements obtained with computational tool developed, in a set of 40 images to four species of plants.

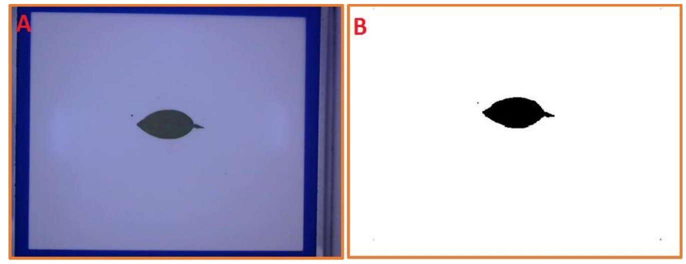

Figure 6. A. Original image with computational tool. B. Segmentation of leaf. Source: Authors.

RESULTS AND DISCUSSION

In order to standardize a methodology to identify leaf area in plants, design and assembly of computational tool and each of modules that composed system of artificial vision were apply; in Figure 4, obtained results are shown. In them is evidenced that it allows to obtain the leafs area with a maximum size of (30 × 30) cm, in addition to count with parameters of lighting controlled whit lid to prevent of lighting environment unwanted situations.

The first stage tested was process of acquisition and preprocessing images, in order to get leaves area in a simple form without distortions that affect measurement. For this reason a contrast adjustment stage was implemented to diminish changes of intensity in images, then in Figure 5 are showed images acquisition results and it is preprocess respectively.

Later, extraction stage of leaf regions was evaluated, having controlled parameters of lighting without depending on external light, it was possible to apply segmentation process through a conventional technique as Otsu method and histogram analysis. Then, results of segmentation process are shown in Figure 6.

Finally, identification stage of leaf area was test by determining area of leaves, through pixels relation to cm^2 as shown in Equation 1. Then, in Figure 7, graph shows interface developed to visualize results.

To validate computational tool, analysis of leaf area of four different species from plants with 10 leaves was apply. Later, it was determined leaf area. The results were compared with results obtained by an expert in agronomy through conventional methods used in the Universidad de Cundinamarca.

Initially, a correlation analysis was identify between developed tool, manual measure and precision scales, demonstrated high correlation for orange tree leaves, with a coefficient of determination 0.9953 with regard to manual method and a coefficient of determination of 0.9768, with regard to method of precision scales, as shown in Figures 8 and 9, respectively.

Likewise, validation allowed demonstrating to lemon tree leaves, high correlation with a coefficient of

Figure 7. Interface graph of user for computational tool. Source: Authors.

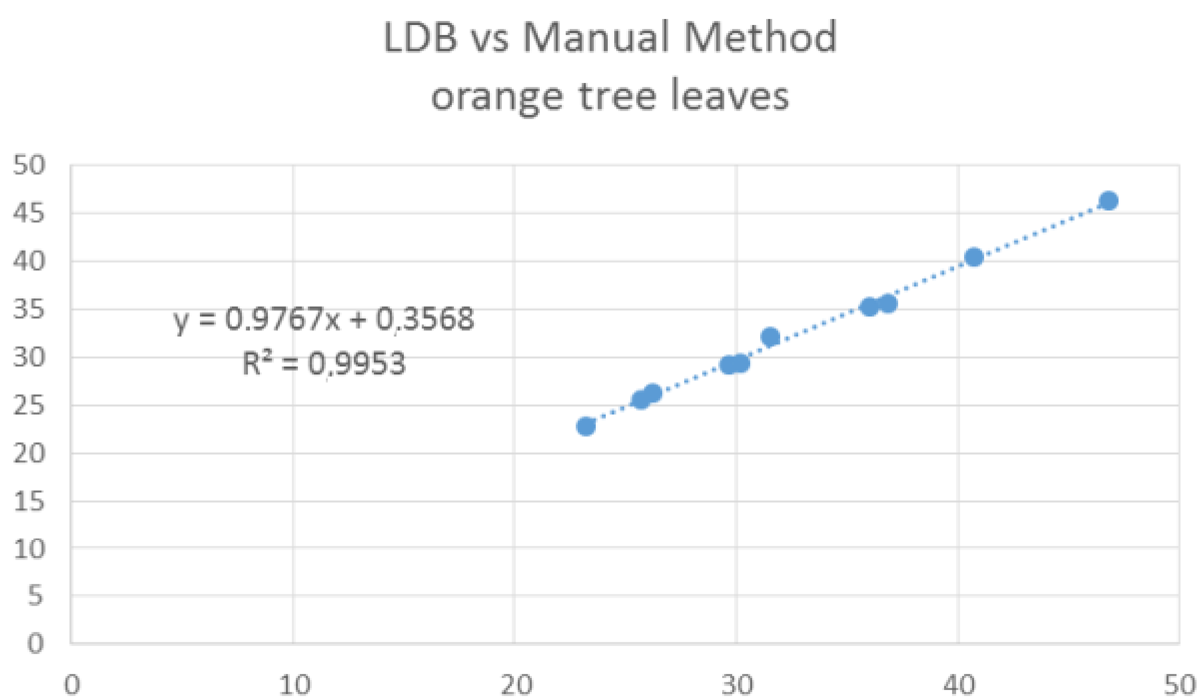

Figure 8. Correlation of computational tool with regard to manual method, for orange tree leaves. Source: Authors.

determination of 0.992 regarding to manual method and a coefficient of determination of 0.9894 with regard to method of precision scale, as shown in Figures 10 and 11, respectively.

Later, validation was apply for almond tree leaves and the test allowed to demonstrate high correlation with a coefficient of determination of 0.992 regarding manual method and a coefficient of determination of 0.9686 with regard to method of precision scales, as shown in Figures 12 and 13 respectively. This test evidenced that for leaves with a size and a weight relatively high differences between implemented methodology and conventional methods are most notorious but with percentages of an acceptable precision.

Finally, the validation was apply to mango tree leaves and test allowed to demonstrate high correlation with a

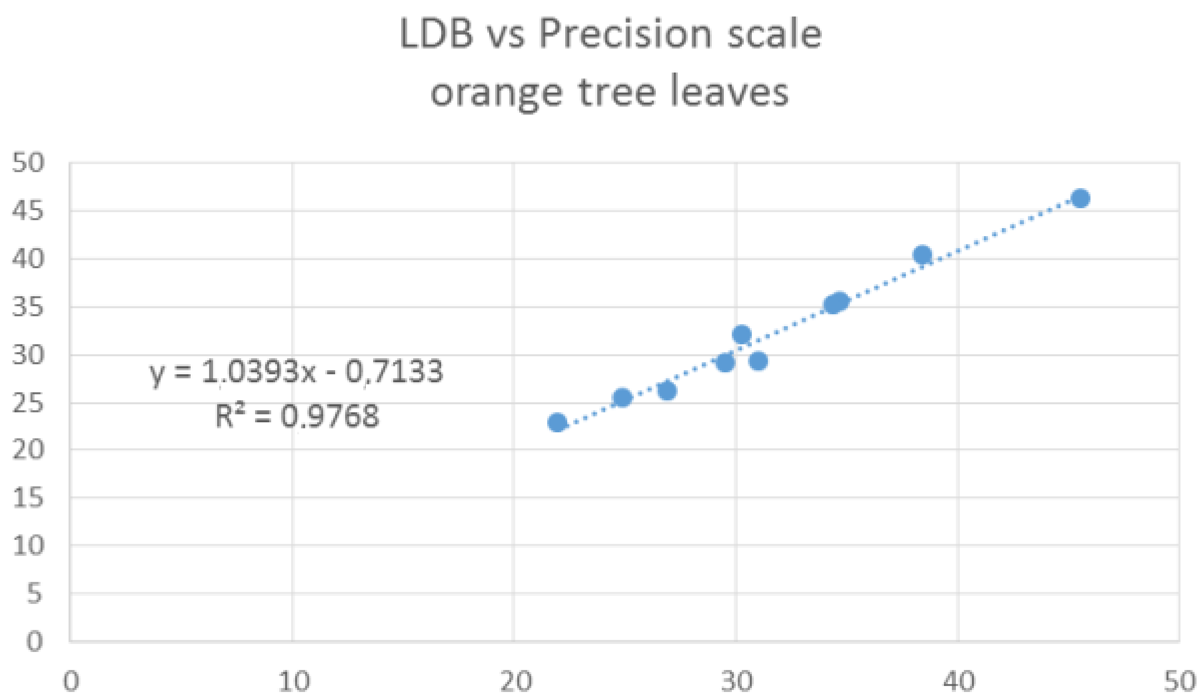

Figure 9. Correlation of computational tool with regard to precision scale, for orange tree leaves. Source: Authors.

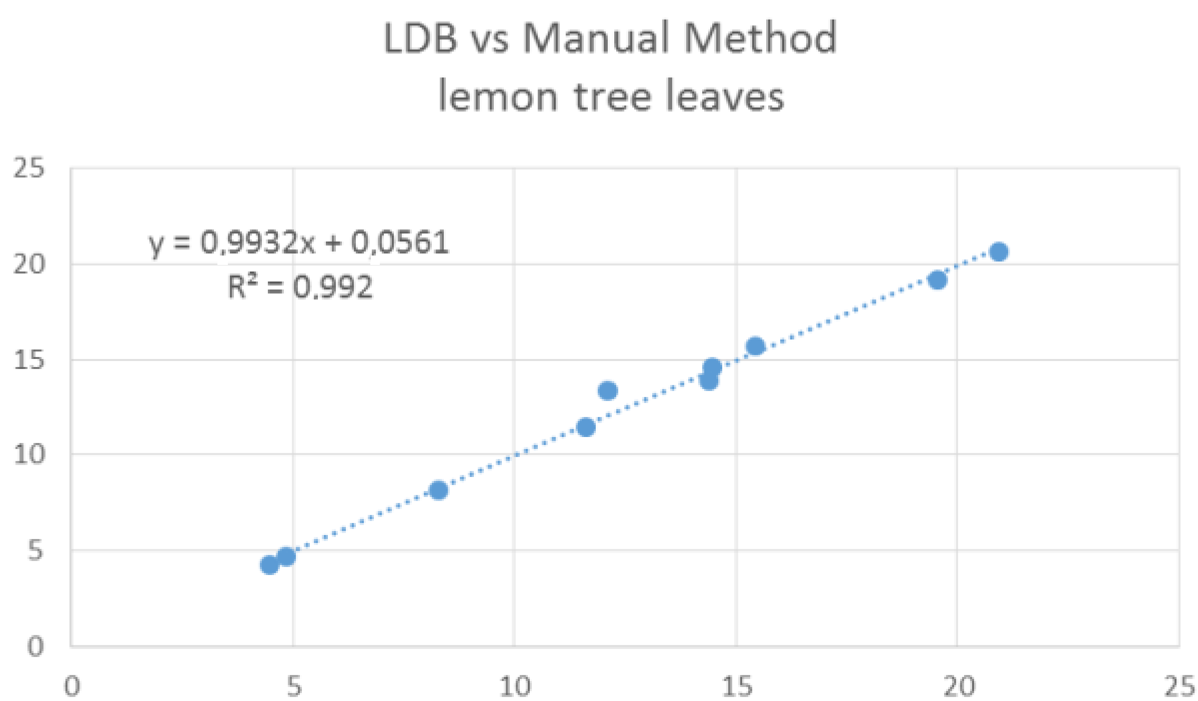

Figure 10. Correlation of computational tool regarding to manual method, for lemon tree leaves. Source: Authors.

coefficient of determination of 0.9997 with regard to manual method and of 0.9965 with regard to precision scales, as showed in Figures 14 and 15 respectively. The validation demonstrated that methodology implemented

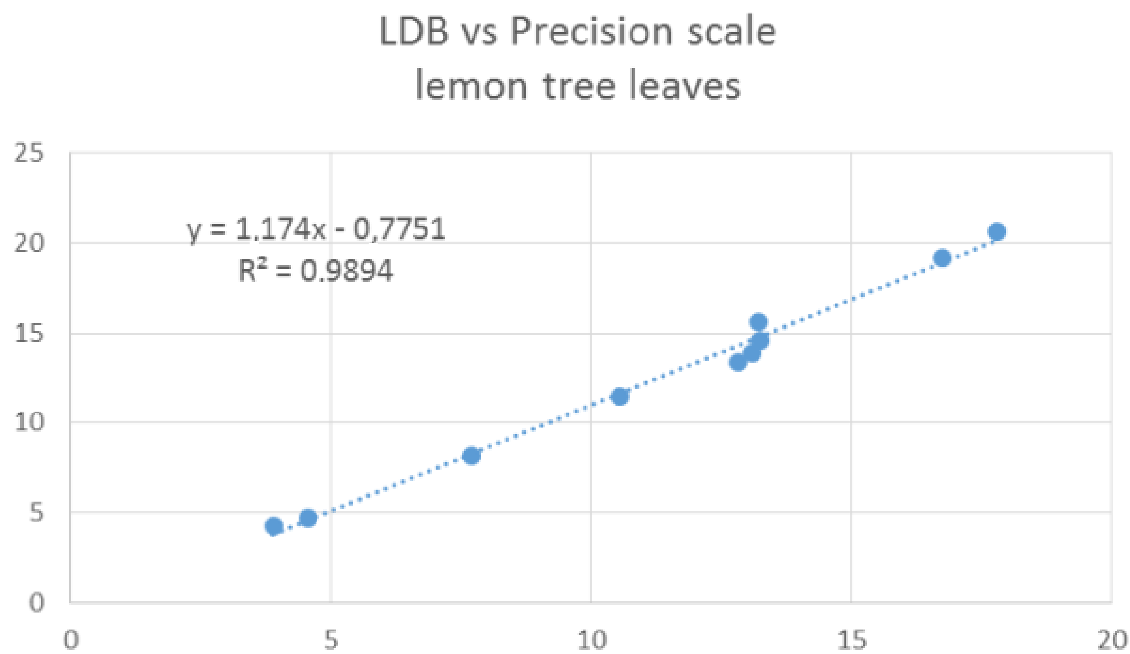

Figure 11. Correlation of computational tool with regard to precision scale, for lemon tree leaves. Source: Authors.

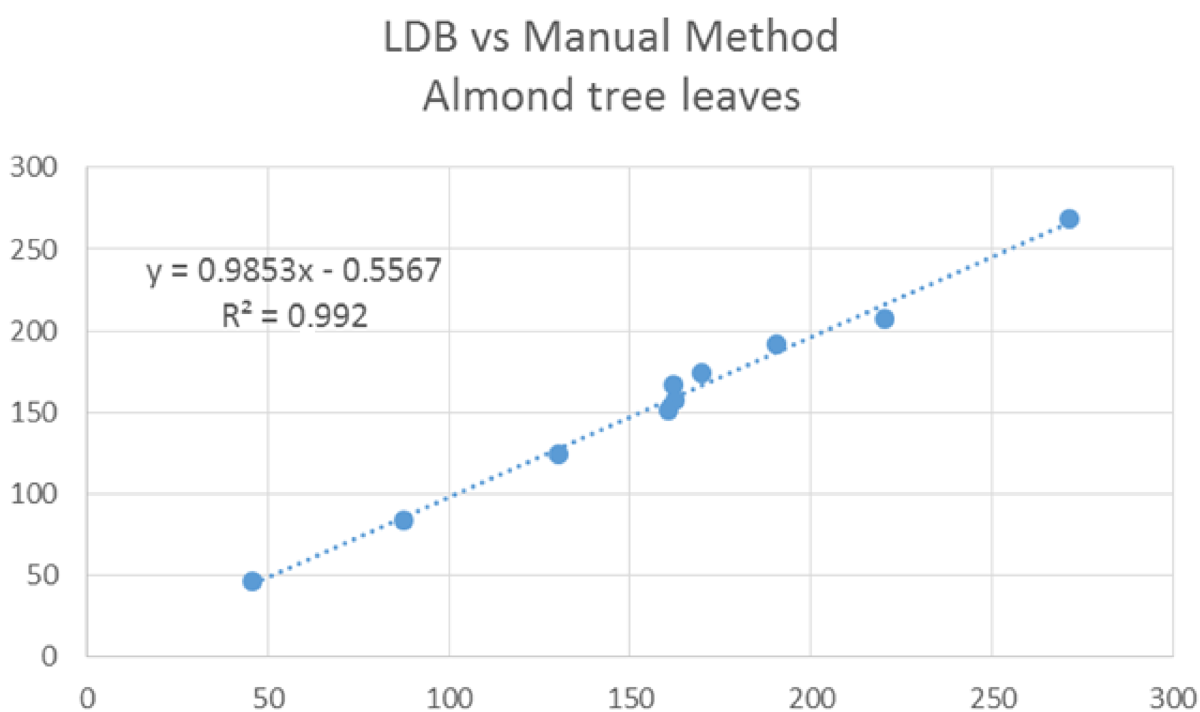

Figure 12. Correlation of the computational tool regarding to a manual method, for almond tree leaves. Source: Authors.

allows technological support for leaf area analysis, due to its high indexes of correlation that it was present for the four plants species.

Finally, validation of computational tool was done, by a variance in three different measurements for every leaf in a set 40 images, then, it showed the variances for every

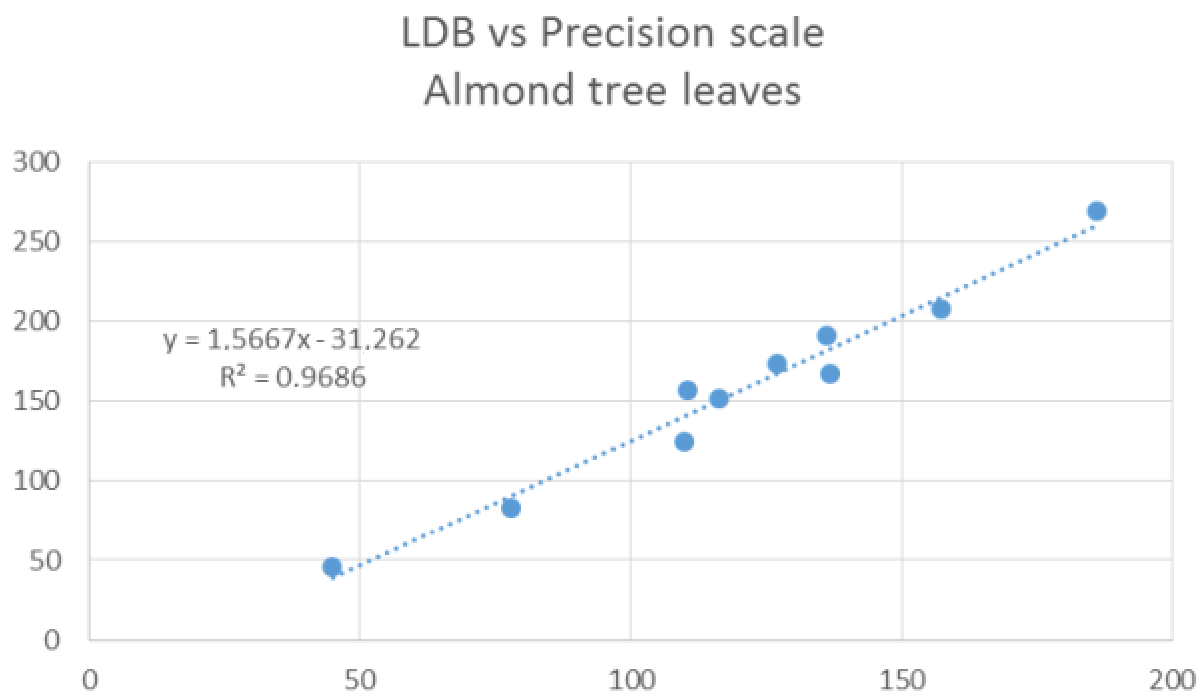

Figure 13. Correlation of computational tool with regard to precision scale, for almond tree leaves.

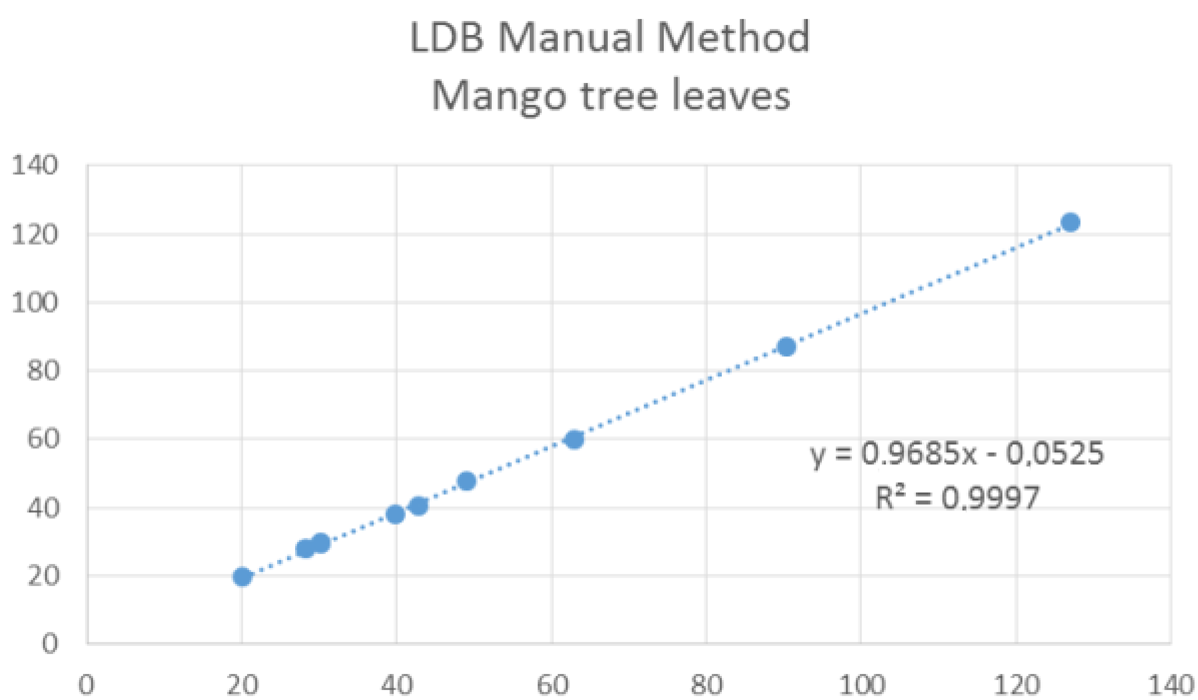

Figure 14. Correlation of computational tool with regard to manual method, for mango tree leaves. Source: Authors.

class in Tables 1 to 4, it was evidenced a variance of 0.00024 for orange tree leaves, 0.007 for lemon tree leaves, 0.008 for almond tree leaves and 0.001 for mango tree leaves, showing precision of algorithm to provide very similar results when it is applied in different occasions for same leaf.

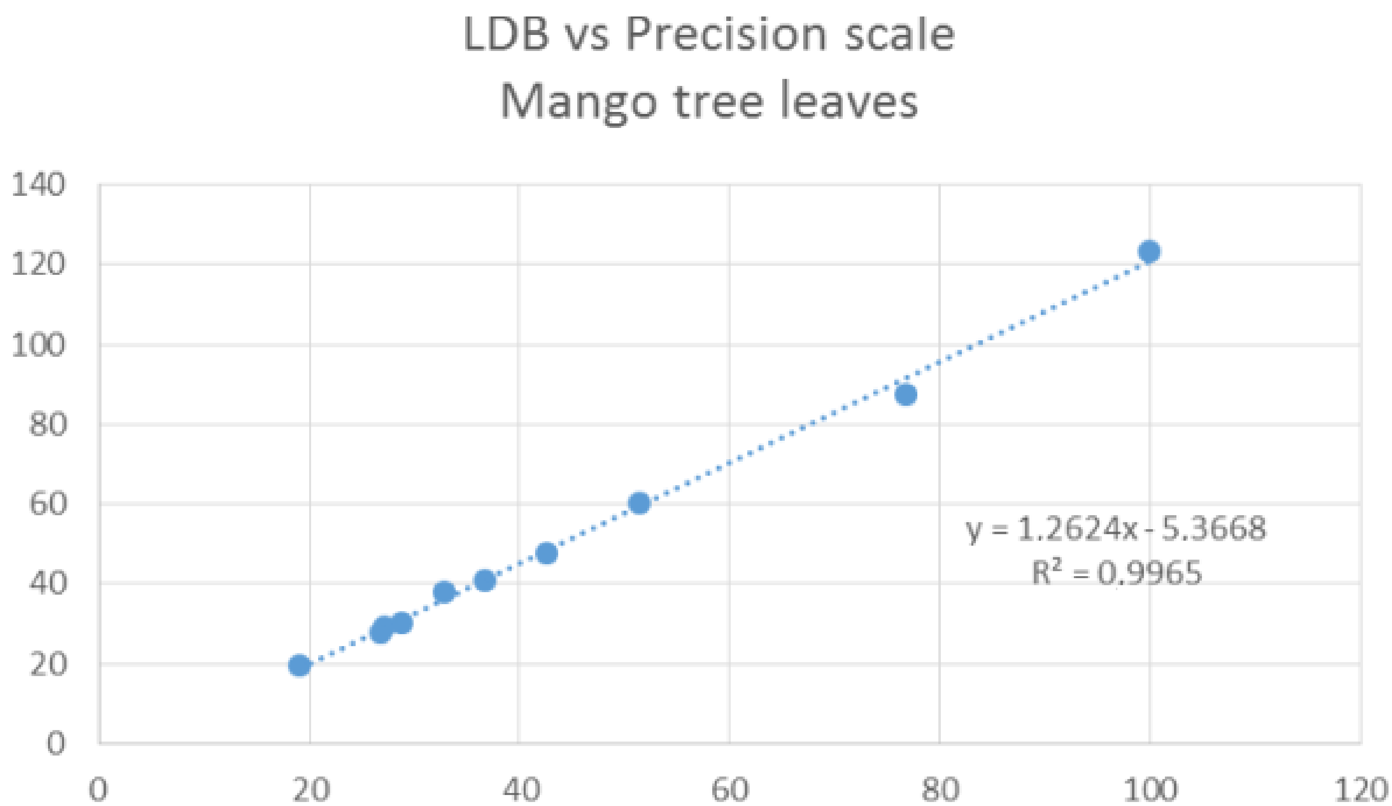

Figura 15. Correlation of computational tool with regard to precision scale, for mango tree leaves Source: Authors.

Table 1. Precision of system (Leaf detector box) for orange tree leaves.

Orange	Module (leaf detector Box)				
	Measure 1	**Measure 2**	**Measure 3**	**Medium**	**Variance**
Leaf 1	22.84	22.86	22.86	22.85	0.000133
Leaf 2	25.63	25.59	25.59	25.60	0.000533
Leaf 3	26.25	26.25	26.25	26.25	0
Leaf 4	32.17	32.14	32.16	32.16	0.000233
Leaf 5	29.14	29.19	29.17	29.17	0.000633
Leaf 6	29.29	29.31	29.34	29.31	0.000633
Leaf 7	35.57	35.56	35.55	35.56	0.0001
Leaf 8	35.32	35.31	35.31	35.31	3.33E-05
Leaf 9	40.4	40.4	40.4	40.40	0
Leaf 10	46.29	46.29	46.31	46.30	0.000133
		Mean variance			0.00024

Source: Authors.

Conclusions

In computational tool development (Leaf Detector Box) for leaf area identification in plants, it was of vital importance adequacy of parameters of lighting, because it must ensure that in process of images acquisition, presence of unwanted objects, impurities or abrupt changes in intensity is minimized. The previous thing facilitated the extraction of leaf, since at present lighting inadequate conditions generates erroneous detections in edges, causing error in measurement. Through developed tool, leaf area was obtained with high precision compared to

Table 2. Precision of system (Leaf detector box) for lemon tree leaves.

Lemon	Module (leaf detector Box)				
	Measure 1	**Measure 2**	**Measure 3**	**Medium**	**Variance**
Leaf 1	4	4.5	4.25	4.25	0.0625
Leaf 2	8.16	8.12	8.16	8.15	0.000533
Leaf 3	4.69	4.69	4.67	4.68	0.000133
Leaf 4	13.34	13.35	13.36	13.35	1E-04
Leaf 5	13.87	13.89	13.85	13.87	0.0004
Leaf 6	15.67	15.68	15.63	15.66	0.0007
Leaf 7	11.45	11.45	11.44	11.45	3.33E-05
Leaf 8	20.63	20.68	20.62	20.64	0.001033
Leaf 9	14.61	14.56	14.54	14.57	0.0013
Leaf 10	19.22	19.22	19.14	19.19	0.002133
		Mean variance			0.007

Source: Authors.

Table 3. Precision of system (Leaf detector box) for Almond tree leaves.

Almond	Module (leaf detector Box)				
	Measure 1	**Measure 2**	**Measure 3**	**Medium**	**Variance**
Leaf 1	46.2	46.15	46.08	46.14	0.004
Leaf 2	83.73	83.73	83.69	83.72	0.001
Leaf 3	268.59	268.63	268.71	268.64	0.004
Leaf 4	157.38	157.41	157.42	157.40	0.000
Leaf 5	151.17	151.28	151.37	151.27	0.010
Leaf 6	191.28	191.3	191.35	191.31	0.001
Leaf 7	173.64	173.67	173.67	173.66	0.000
Leaf 8	124.25	124.39	124.43	124.36	0.009
Leaf 9	166.91	167.18	167.33	167.14	0.045
Leaf 10	207.44	207.34	207.46	207.41	0.004
		Mean variance			0.008

Source: Authors.

Table 4. Precision of system (Leaf detector box) for mango tree leaves.

Mango	Module (leaf detector Box)				
	Measure 1	**Measure 2**	**Measure 3**	**Medium**	**Variance**
Leaf 1	19.64	19.63	19.64	19.64	0.00003
Leaf 2	27.73	27.74	27.78	27.75	0.00070
Leaf 3	30.02	30.04	30.02	30.03	0.00013
Leaf 4	29.18	29.21	29.2	29.20	0.00023
Leaf 5	38.22	38.22	38.21	38.22	0.00003
Leaf 6	40.75	40.78	40.7	40.74	0.00163
Leaf 7	47.58	47.62	47.58	47.59	0.00053
Leaf 8	60.02	60.09	60.06	60.06	0.00123
Leaf 9	87.31	87.3	87.3	87.30	0.00003
Leaf 10	123.44	123.39	123.43	123.42	0.00070
		Mean variance			0.001

Source: Authors.

conventional methods used in Universidad de Cundinamarca by an expert. The precision was evaluate by determination coefficients, for case of orange tree leaves, there was obtain a coefficient of determination of 0.9953 with bias of 0.3568 cm in measure, with regard to manual method and 0.9768 with bias of 0.7133 cm, with regard precision scale method. Likewise, it was apply to lemon tree leaves, obtaining a coefficient of determination of 0.992 with bias of 0.056 cm, with regard to manual method and 0.9894 with bias of 0.7751 cm, with regard to precision scale method. Later, the study was apply to Almond tree leaves, obtaining a coefficient of determination of 0.992 with bias of 0.5567cm, with regard to manual method and 0.9686 with bias of -31.36 cm, with regard to precision scale method. Finally, the mango tree leaves were evaluate with which obtained a determination coefficient of 0.9997 with bias of -0.052 cm, with regard to manual method and 0.9965 with bias of -5.36 cm, with regard to precision scale method, demonstrating good application of tool for the four leaves species. In conclusion, it was determined that methodology implemented, presented very approximate measures with regard to manual method with a max bias of 0.55, evidencing its good performance. In addition, it was determined that precision scale method has more imprecision in measure, due to cuts of known measure on leaf. Finally, results obtained with algorithm were validate with a variance analysis (ANOVA), which obtained a mean variability in measurements of 0.00024 for orange tree leaves, 0.007 for lemon tree leaves, 0.008 for almond tree leaves; and 0.001 for mango tree leaves. This demonstrating algorithm precision to provide identical results when it was apply for same leaf in different positions on measuring area, which increases repetitively in results. For future investigations, it was propose determined nutritional deficiencies in plants as information of color and present damages in leaves. As well, provide a technological support to in determination of indexes of growth.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors are thankful to Universidad de Cundinamarca for the financial support and for the expert staff in detection of leaf parameters. Thanks to Professor Adriana Bendek for her valuable work in the review of style of the paper and to Professor Cristina Mendoza for her valuable manual analysis collaboration for leaf area determination in plants, which allowed validation of proposed system?

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