Method for estimating leaf coverage in strawberry plants using digital image processing

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A B S T R A C T

In farming the measurement of leaf coverage is considered as an exhaustive task for the researchers due to most of the time they do not have access to the adequate tool for this purpose. A new algorithm, implemented in this investigation, allows to estimate by means of a non-destructive method, the leaf coverage value of strawberry plants (*fragaria* x *ananassa*) of the cultivar Albion in the Cajicá region, Colombia, by using digital image processing techniques (DPI). The DPI based technique includes the smoothing, dilatation, contour detection, threshold and edges detection operations. The image acquisition system was conducted by means of photographic images in plants in study, directly from the beds of the crop and the captures were subsequently processed through the proposed algorithm. The obtained results show the measured values of the plants leaf coverage in cm^2, with up to 90% of accuracy. This system gives an important contribution to the crop evolution analysis by computational tools, making easier the monitoring work.

Método para estimar a cobertura foliar das plantas de morango usando processamento de imagem digital

R E S U M O

Na agricultura a medição da cobertura de folha é considerada como uma tarefa exaustiva para os pesquisadores, devido na maioria das vezes eles não terem acesso à ferramenta para este proposito. Um novo algoritmo, implementado nesta investigação permite estimar, por meio de um método não destrutivo, o valor de cobertura foliar das plantas de morango (*fragaria* x *ananassa*) da cultivar Albion na região de Cajicá, Colômbia, usando técnicas de processamento digital de imagens (PDI). A técnica baseada em PDI inclui as operações de suavização, dilatação, detecção de contorno, limiarização e detecção de bordas. O sistema de aquisição de imagem foi realizado por meio de imagens fotográficas nas plantas em estudo, diretamente dos canteiros da cultura e as capturas foram posteriormente processadas mediante o algoritmo proposto. Os resultados obtidos mostram os valores medidos da cobertura foliar de plantas em cm^2, com até 90% de precisão. Este sistema proporciona uma importante contribuição para a análise da evolução das culturas por ferramentas computacionais, tornando mais fácil o trabalho de monitoramento.

Introduction

Often, many of the practices adopted in agricultural crops, including strawberry crops, are rigorously preventive measures, to ensure the best health and nutritional plants condition, thus ensuring a good market acceptance for the crops (Lallana & Lallana, 2014). These practices include the leaf coverage measurement this data is required in horticultural and ecological sciences to studies the plant´s growth rate, the light amount absorbed, the domain percentage on the plant species in its ecosystem, the erosion measurement, among others (Roose, 1996; Wilson, 2011; Fu et al., 2012; Gu et al., 2013; Rangeland & Riparian Habitat Assessment, 2015).

The importance of leaf coverage estimation sets to determine the varieties that generate the best crop yields and their adaptation to the environment. Several studies submitted by Damgaard (2013), Herpigny & Gosselin (2015) and the University of Idaho (2015) showed that leaf coverage estimation by mathematical models is not an easy task to perform, due to the measurement variation caused by the weather, and the possible presence of pest and diseases, that prevent the determination of an accurate estimation. The research carried out by Weber et al. (2013); Karl et al. (2014) and Lehnert et al. (2015). Showed good leaf coverage estimation through satellite images, even though, this data acquisition system has several limitations, such as: the geographic area restrictions, weather conditions that could prevent taking a good photograph, the service cost and the date of the captured images.

On the other hand, there is evidence in the study of Laliberte et al. (2007) of leaf coverage estimation using digital camera and image processing of the vegetation present in the arid region of the United States, obtaining correlation coefficients between 0.88 and 0.95. However, this method lack the necessary qualities to introduce it in other type of scenarios, specifically when calibrating the scale reduction of pixels in the obtained images.

Taking into account the foregoing, this study proposes to introduce a new value estimation algorithm of leaf coverage, for the cultivar Albion strawberry plants, by using digital image processing techniques (PDI), in order to offer researchers and producers a new way to obtain this data, and track the farming process in a quick and indirect way. The new algorithm will work in field crops and greenhouses as well, without using satellite images, and will allow the usage of digital cameras and/or drones as imaging tools.

Material and Methods

This study performed in the Nueva Granada Campus' garden centers, which belongs to the Nueva Granada Military University in Cajicá, Cundinamarca, Colombia, at an altitude of 2.560 m, 14 °C of average temperature y 85% of average relative humidity. Strawberry plants of the cultivar Albion were randomly selected, and conducted during the respective period of analysis, seeking to remove the diseased leaves or those that suffer from senescence. A wooden stake identified with a squared white cardboard (side = 3 cm), was used to standardize the studied scenario.

The obtained images were taken by means of a digital camera, which most relevant technical specifications include: 20 megapixel resolutions, automatic adjustment of focus, brightness and contrast, and scan speed of 250 Hz. Each capture is perform manually, at a height of 1 m from the ground, thus avoiding the use of the digital zoom. The images were taken between 9 a.m. and 12:00 p.m., under the regional typical weather conditions (partially cloudy sky).

A new algorithm for the leaf coverage estimation was implemented, it was developed in a Graphical user interface (GUI) application by using C# programming language and the bookstore Emgu CV, which allows the usage of DIP Techniques. The application loads the acquired image, runs the procedure of the proposed algorithm and presents the leaf coverage estimation. This application works through a desktop computer under the following specifications: AMD Athlon II X245 (2 x 2.9 GHz), RAM memory of 4GB DDR2, ATI Radeon HD 4350 and Windows Operating System 8.1 Update 1 (64 bit). The Figure 1. Shows a general outline of this methodology.
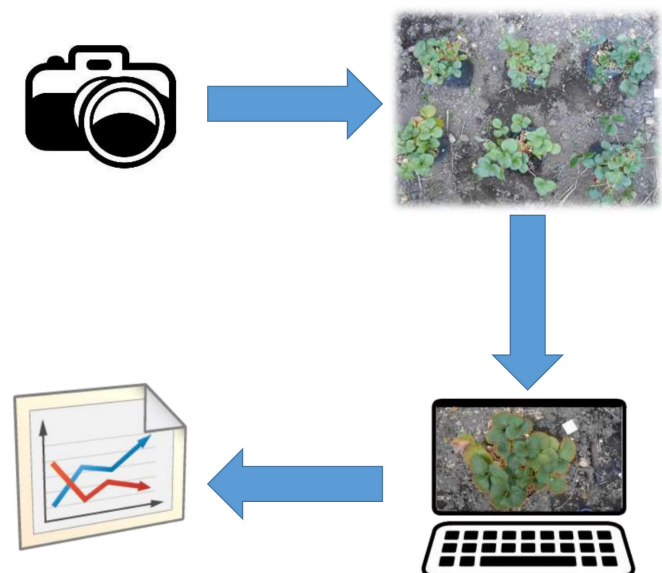

Figure 1. Illustration of working conditions

Results and Discussion

Aiming to leaf coverage estimation, it is proposed an algorithm which identifies a pattern of the know area, in a way that makes possible pixel counting in green regions, that relate the strawberry plant's leaflets. It performs a pixel-millimeter conversion and shows leaf coverage calculation in cm^2. Figure 2 shows the main flow diagram of the algorithm applied.

Taking advantage of the high-resolution images taken by the camera, the regions of interest were digitally clipped, highlighting always the top or vertical view of the studied site(s), together with the stake for the standardization of the scenario. The images were taken manually, as shown in Figure 3.

When loading the image of interest, pre-processing methods are used to improve segmentation. The first consist in the green hue ranges determination, to distinguish the leaflets. The Application performs an image data conversion from the traditional device format RGB (Red, Green, Blue), to HSV format (Hue, Saturation, Value), this one allows to
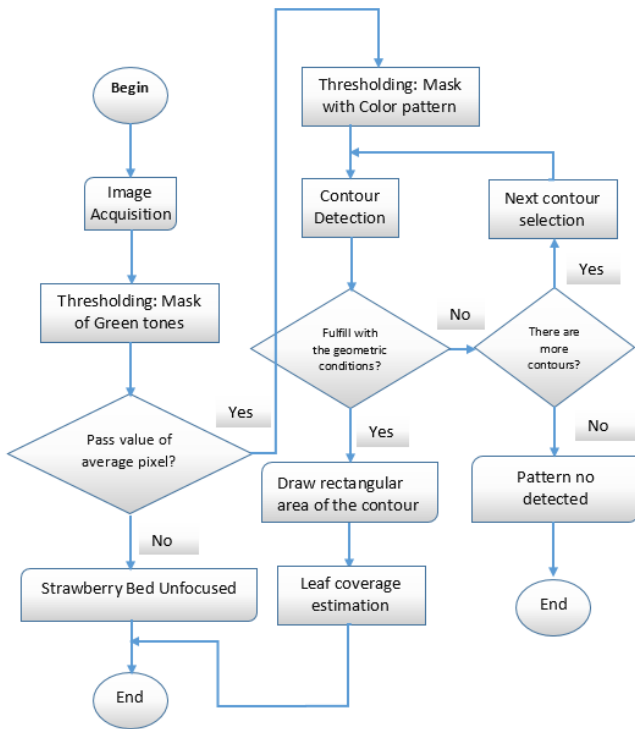
Figure 2. Flow diagram of the algorithm implemented

Figure 3. Ideal Capture for leaf coverage estimation in strawberry plants, in the proposed algorithm

differentiate more easily the colors in an image. To obtain the mask of green shades process of threshold is performed, based on Eq. 1, which returns a vector with the data that define the resulting image.

$$dst(I) = \begin{cases} 255 \to lowerb(I)_0 \leq src(I)_0 \leq upperb(I)_0 \\ 0 \to \text{of the opposite} \end{cases} \quad (1)$$

where: dst(I) corresponds to the vector or image returned, the size of each pixel of the $src(I)_0$ input image or vector, and $lowerb(I)_0$ and $upperb(I)_0$ the lower and upper limits of the HSV color space respectively. Eq. 2 calculates the main intensity of the resulting image, binary type, called mask.

$$Avg = \frac{\sum_{i=0}^{n} src(I)_0}{n} \quad (2)$$

where $src(I)_0$ is the magnitude of each of the pixels of the mask obtained above and n the total number of pixels that make up the picture. With this value, it is possible to determinate if the concentration green shades in the image meets with the 10% of total intensity in the image being analyzed.

If the condition is met, the mask applies a smoothing filter in order to considerably reduce the noise generated by the pre-processing operation, using the Eq. 3 to carry out the image transformation.

$$K = \frac{1}{2 \cdot ks} \begin{bmatrix} 111 & \cdots & 11 \\ \vdots & \ddots & \vdots \\ 111 & \cdots & 11 \end{bmatrix} \quad (3)$$

where ks is an odd value, equivalent to the size of the filter opening. The filter reduces the contours obtained area; therefore, it applies the morphological operation of dilation using Eq. 4, thereby offsetting the effect of the previous operation.

$$dst(x, y) = \max_{(x',y'):element(x',y') \neq 0} src(x + x', y + y') \quad (4)$$

where dst(x,y) is each one of the pixels of the resulting image in the plane x,y of the processed image, src(…) corresponds to the same exact pixel in the original image and x',y' denotes the location of the closest neighbor pixel. Figure 4B displays the result of the methods previously deployed for an original image belonging to this study, illustrated in Figure 4A.

From the original image displayed in Figure 4A, the contour of the implemented pattern is obtained, standardizing on the scene, applying the Eq. 5. This method segments the regions of white shades, as can be seen in Figure 4C.

$$dst(x, y) = \begin{cases} src(x, y) & \text{si } src(x, y) > Th \\ 0 & \text{on the contrary} \end{cases} \quad (5)$$

where each of the pixels of the resulting image is dst(x,y) in the plane x,y of the image being analyzed, src(x,y) corresponds to the analyzed pixel at that point of coordinates and Th is
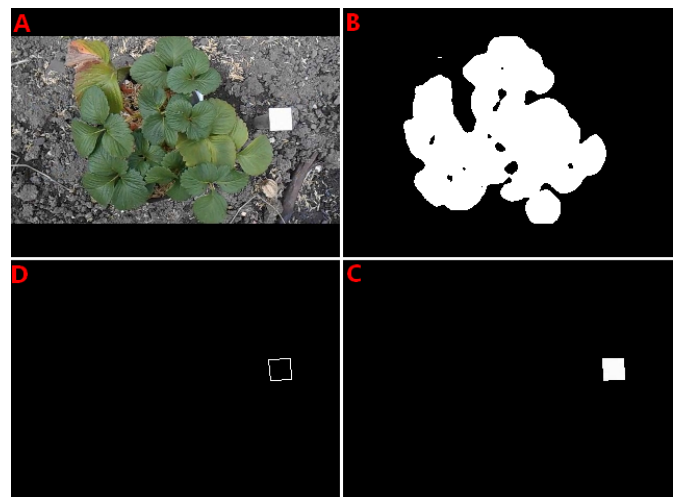

Figure 4. Image composed by the most relevant stages of the proposed algorithm

the intensity of color to make the threshold. Subsequently, there are the external contours of the resulting image, through the algorithm proposed by Suzuki & Abe (1985), which generates a vector of points with the coordinates of each of the contours detected, as seen in the Figure 4D. With this list is necessary to select each of the contours, in order to conceal by its geometry and its size . The instructions in this method include condition, referring to the number of vertices of each contour (4 in this case) and verifying the interior angle that forms the corners that intersect (between 85 to 95°), ensuring that the detected contour corresponds to a rectangle (Figure 4D). In the event that, no contour will satisfy the requirements of geometry, a result is presented in the application stating that it has not detected any pattern of standardization.

The measurement of the leaf coverage area in the filtered contours, is calculated with the green theorem, which stablishes the relationship between the comprehensive line of a closed curve C and a double integral about a region D rounded in C, defined by Eq. 6 The leaf coverage estimation is obtained by Eq. 7.

$$\oint_c M \, dx + N \, dy = \iint_R \left(\frac{\partial N}{\partial x} - \frac{\partial M}{\partial y} \right) dx \, dy \qquad (6)$$

$$FC_{[cm^2]} = FC_{[px^2]} \cdot \frac{PA_{[cm^2]}}{PA_{[px^2]}} \qquad (7)$$

where $LC_{[cm2]}$ is the leaf coverage area in square centimeters, $LC_{[px2]}$ leaf coverage area in square pixels, (figure obtained by the sum of the pixels of the main mask, corresponding to the Figure 4B). The $PA_{[cm2]}$ rectangular area of the pattern in cm^2, known data and delivered by the user of the application and the area of the pattern in square pixels, data obtained by the area occupied by the contour of the pattern detected and plotted, $PA_{[px2]}$.

To validate the algorithm accuracy, the leaf coverage area of each leaflets of the plants was obtained by measuring their length from base to apex. To obtain an equation that use only this variable, 30 leaflets of different morphology were uprooted then the images were acquired by scanning each one, and by means of the software Gimp 2.8 and it was possible to obtain Eq. 8, through the regression technique by least squares, resulting in an un $R^2 = 0.9988$.

$$A_F = 0.8241 \cdot l_f^{1.7969} \qquad (8)$$

where l_f corresponds to the length of the leaflet and the estimated leaf area, A_F. However, the technique is destructive and it was used to corroborate the findings of this investigation.

When running the technique mentioned above, a statistical study of the obtained data is conducted, illustrated in Figure 5. According to the box-plot, there is a prevalent trend in the studied leaf dimensions and measurements made to each plant do not reflect any condition of symmetry.

To validate the results, 10 photographs were taken per plant to obtain the average value of leaf coverage. In accordance with
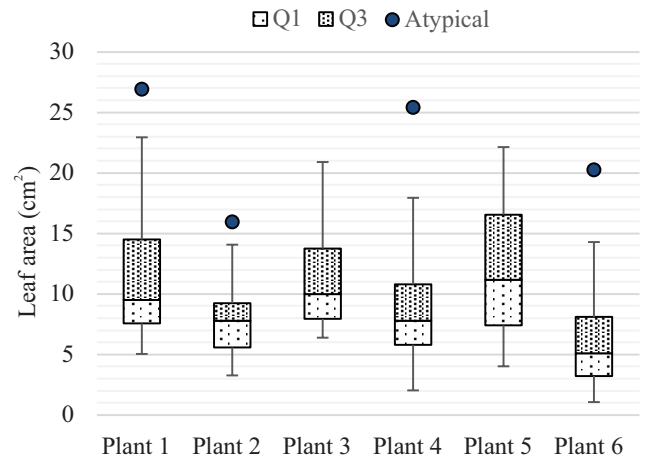

Figure 5. Individual leaf coverage estimation for each of the leaves in the studied plants.

the h one of the studied plants are, the magnitude of standard deviation and the standard error of the mean indicate that the proposed algorithm has outstanding precision, regardless the height at which it is carried out the photo capture. The obtained data obtained showed that the captures are representative, regardless of the height at which are the leaves of each one of the studied plants are.

To estimate the algorithm accuracy, we calculate the relative error of the leaf coverage (LC) considering this as theoretical data, the summation of the leaf area of the leaflets that are directly exposed to ultraviolet light. Measurements returned by the algorithm were taken as experimental data, in accordance with Eq. 9. Figure 6 represents the results.

$$accuracy = \left(1 - \frac{LCE - \overline{x}}{LCE} \right) \cdot 100\% \qquad (9)$$

Table 1. Leaf coverage (LC) of each one of the studied plants, depending on the algorithm implemented

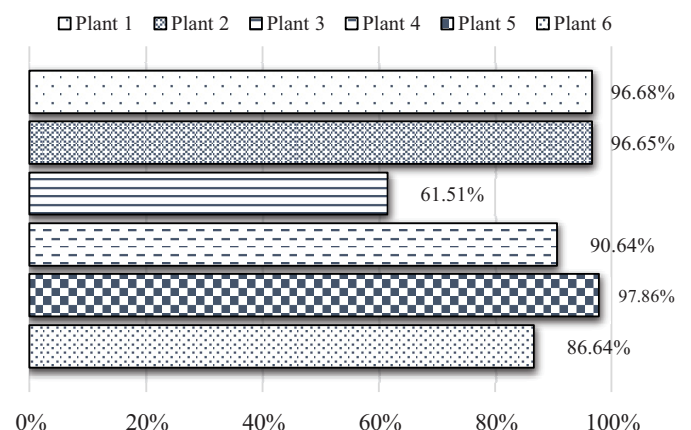| Plant	Samples	Media	Standard deviation	SE	Estimate of LC
			cm²		
1	10	421.1078	5.0801	1.6064	407.5735
2	10	234.7592	4.6736	1.4779	227.1498
3	10	491.3475	1.9553	0.6183	354.7839
4	10	235.3215	3.3193	1.0496	259.6191
5	10	287.2889	10.1175	3.1994	379.1809
6	10	223.7305	5.3946	1.7059	258.2316

Figure 6. Accuracy of the data obtained by the proposed algorithm

The measurements with the lowest accuracy percentages correspond to plants whose leaflets are positioned at different heights between them as plants 3 and 6, unlike plants 1 and 5, whose leaflets are on the same average height. This phenomenon occurs due to the limitations of the available information, because it is not possible to obtain the depth of objects using only one camera to acquire data. Despite this fact, the leaf coverage estimation fulfilled its purpose of easily analyzing entire strawberry plants beds with the proposed algorithm, adapting only a pattern of reference to the state of images capturing.

The implemented method allows obtaining the leaf coverage value easily and affectively, without relying on the mathematic model variables (Damgaard, 2013; Herpigny & Gosselin, 2015 and University of Idaho, 2015), the economic investment, availability, weather conditions and updating of satellite images (Weber et al., 2013 and Karl et al., 2014). The investigation made it possible to improve the work done by Laliberte et al. (2007), obtaining the photographic captures by using a pattern of known length, and introducing it in the scenario avoiding the pixel scale reduction calculation in each obtained image.

Finally, this research could be complemented with other related works; it would be possible to combine this work also with some other image acquisition techniques. The work presented by Córcoles et al. (2013) presents the option of automate this task, monitoring with drones, and GPS incorporated system with mission routes covering the strawberry plants area, especially if cultivated in the field (Xiang & Tian, 2011). In addition, it could help researches that requires the estimation of leaf coverage to study other abnormalities presents in plants through their leaflets (Demirsoy, 2009). Similarly, the algorithm meets the requirements for its portability on mobile devices, in accordance with current trends in technological consumption (Li, 2014).

Conclusions

1. It was possible to propose and implement a robust, accurate and exact, algorithm to estimate the leaf coverage of strawberry plants from the variety Albion, applying a non-destructive methodology, using only a digital photograph, a pattern with known length measurements and digital processing of images.

2. The implementation of the algorithm in the GUI is a good alternative for researchers, to monitor the growth and yield of strawberry plants, at a lower cost and almost no maintenance of the system, in comparison to other solutions offered in the scientific community and in the market.

3. This work allows future leaf coverage researches by similar methodology, keeping in mind that it can be completely compatible with drones and many different kind of cameras, in the field as in the greenhouse.

Acknowledgments

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