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Image-based automated leaf area calculation using OpenCV

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Abstract

Analyzing RGB images with the help of computer vision is an affordable and reliable tool to study plants. This approach is becoming widely used due to the low cost of high-resolution RGB cameras and the existence of open source software [5]. The main purposes are phenotyping, development observation and detection of illnesses among different crop types for both scientific purposes and breeding. Nowadays, leaf area extraction, leaf segmentation and 3D reconstructions of plants are popular problems solved with image processing and machine learning.

This thesis describes an algorithm for automated leaf area calculation in captured images. It explains the program's features and compares the results with the calculations of specialists. Finally, a usable GUI application is designed to help Tartu University lab workers with automation of a manual task.

CERCS: T111 Imaging, image processing

Keywords: image processing, leaf segmentation, OpenCV

Piltidel põhinev automaatne lehtede ala arvutamine OpenCV abil

Lühikokkuvõte

RGB kujutiste analüüsimine arvutinägemise abil on taskukohane ja usaldusväärne vahend taimede tuvastamiseks ja nende omaduste hindamiseks. Seda lähenemist kasutatakse laialdaselt kõrge resolutsiooniga RGB-kaamerate madalate kulude ja avatud lähtekoodiga tarkvara olemasolu tõttu [5]. Peamised eesmärgid on taimede fenotüpiseerimine, arengu jälgimine ja haiguste avastamine erinevate kultuuriliikide vahel nii teaduslikul eesmärgil kui ka aretamiseks. Tänapeval on lehtede ala ekstraheerimine, lehtede segmenteerimine ja taimede 3D rekonstrueerimine populaarsed probleemid, mis on lahendatud pilditöötluse ja masinõppega.

Käesolevas töös loodi automaatselt toimiv lehtede pindala arvutuse algoritm, mis kasutab pildistatud piltide ja arvutab lehtede pindala. Töö selgitab programmi omadusi ja võrdleb tulemusi spetsialistide arvutustega. Lõpuks on kasutatav GUI rakendus mõeldud selleks, et aidata Tartu Ülikooli taimsete signaalide uurimisrühma töötajatel manuaalülesande automatiseerimist.

CERCS: T111 Pilditehnika

Märksõnad: pilditehnika, lillelehte segmenteerimine, OpenCV

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Acronyms

- ${\bf ROI}\,$ Region of interest
- **WBI** White background images
- **BBI** Black background images
- LAB CIELAB color space

1 Introduction

Water resources globally are in danger and we need to protect them in multiple ways. Agriculture is a vital source of food for humankind, yet it requires a lot of water for irrigation [1]. Work is done in directions of improving the protection of harvest, decreasing the amount of lost crops, and breeding new plant species that would be more efficient with their yield, both of which would decrease the pressure on the water supply in the region. In a bid to to improve and streamline the development of better quality crops, technologies bring their benefits to this field. With increase of production, both in-labs and on a commercial scale, new devices for growing, collection and controlling of the products are introduced.

Techniques such as image processing and computer vision are used in a variety of scientific fields, as well as medicine and manufacturing. In our particular case, control of crops' cultivation and plant growth monitoring became an important and widespread practice. Due to the enormous size of growing fields and continuous increase in amounts produced, keeping track of every plant is an extremely time-consuming process. However, being able to notice the spread of drought or disease and examine the crop before harvesting could save a huge amount of resources. While geneticists and breeders are working on creating more efficient and resistant crops, different modern technologies help them to achieve the goal [6].

1.1 Gas exchange device

One of the major assessment techniques used in our university laboratories is the measurement of gases coming in and out of plants. For that purpose, a unique device was developed by Tartu University Plant Signal Research Group [4]. This device has multiple closed gas exchange chambers where you can fit a whole unscathed plant. Usually used plant is *Arabidopsis thaliana* - the model organism in plant biology [8]. The device can constantly track the change in air moisture, carbon dioxide and oxygen levels and other various measurements simultaneously. It is done inside multiple chambers with various controlled growth conditions for several plants. In other words, by taking constant samples of air in chamber it is possible to measure a change in air composition. This data helps in understanding of important behaviours and properties of a plant in question. The acquired information of stomatal responses is a relative data dependent on a surface area of a crop. Area is important because the amount of gases exchanged is proportional to the plant leaf area. Combining the relative information and calculated area will provide researches with quantitative specific data about the observed type of plant. Moreover, an approximate area of a plant is needed for the initial setup of gas exchange machine.

1.2 Problem statement

Using the advantage of *Arabidopsis thaliana* [8] being a small weed with flat leaves we can take a picture of it from the top and estimate the surface area, which is currently done manually in a time-consuming way. Different graphical editors can be used to find the area of the plant and reference object in pixels. Knowing these areas, real surface area of a plant can be calculated and later used for research purposes. My task is to automate the process which uses pictures of plants and provides a calculated surface area. Such a solution will have multiple benefits for all of its users. The assumption is that this program will both save time and increase the precision of the process (as manual calculations can vary from person to person). In addition, it might become a standard used by various research groups and introduce a certain level of confidence in the results across the board.

1.3 Selected tools

It was decided to use open source development language (Python) and popular library of programming functions (OpenCV) [7]. Python benefits from quick and easy development and testing of algorithms, whereas OpenCV gives an access to many real-time computer vision techniques applicable for images. One advantage of this combination of choices is a possibility to create a simple standalone computer application working without the requirement of side programs running alongside it, need to import external libraries on the fly or constant access to the Internet. As an application for lab workers it needed several specific features: for example, an operator needs a possibility to clearly observe the result and make corrections by adding or removing specific regions of a plant from calculations. Using graphical user interface user can control program to increase precision of the results.

2 Acquired data

All the files used during developing, calibrating and testing, were acquired from the dataset of one of the Plant Signal Research Group actual experiments [4]. Multiple sets of images done during year 2018 were used for the purposes of this paper. Each set has its own date of creation and various number of images inside, varying from 5 to 50. All images have been taken under relatively similar conditions and conform to the specific set of rules described in further sections.

2.1 Camera setup

The camera that was used for all of the shooting is Sony DSC-RX100. It was connected to a shaft with adjustable level of height relative to the surface of the plant. Camera was turned downwards to take images of a plant from the top, due to the fact that this is the best perspective for estimation of leaf area for rosette plants. The vertical shaft was used to change distance from the camera to the plant, which allowed to take pictures of plants of different size. However, that also meant that the size of the same object could be different depending on position of camera, and in order to negate that, a paper object of fixed sized was placed next to the plant, as close to the plane of the growth of the leaves as possible. It was used as a reference point to normalize the size of plants which photos were taken from different heights. Additional lamps were used to provide constant illumination level. Initially the surface beneath the plant and its pot ("the background") used to be fully white. It had a detrimental effect on the output colour range and luminescence of images. To decrease the amount of reflections and their impact on the photos taken, a new matte black surface is used nowadays.

2.2 Image description

The output RBG images have digital dimensions of 5472 by 3648 pixels. Vast majority of the images have a very similar composition, namely a pot with a plant on a uniform white or black background, and a reference paper near the plant Fig. 2.1. The pot is a square white plastic container with a side size of 10 centimetres. The container has four cuts on its sides for a glass plate with a hole in the centre. The plant always initially grows through this hole. During photo shooting operator have often added a reference paper with known dimensions on top of a pot for further image processing. For this purpose, it was chosen to use a piece of millimetre paper with a lined grid on it with the area of 3 cm². This initial choice had multiple drawbacks due to its physical fragility: bends, folds and fading of a paper quickly impacted its observed size that was paramount to be kept constant, which led to the need for replacement. During the program development, a new type of reference has been introduced. As it can be observed from the more recent photos, the new tool is in colour blue and made from plastic.

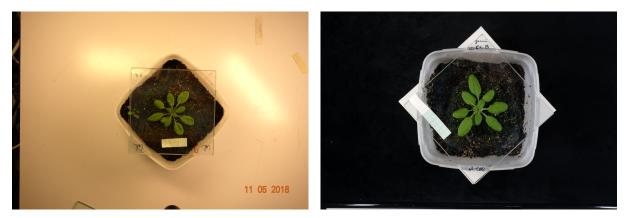


Figure 2.1: Example images with white (left) and black (right) background.

2.2.1 Noise

While taking pictures, different foreign objects and changes in environment can become an obstacle for image processing algorithm. The most frequent occurrence of such interference were cases when people used to leave their hands on a table holding a pot. In addition to that, markers and scissors of different colours present in the picture at times can also be counted as part of a plant by mistake. The glass plates used for covering reflect light and sunlight coming from outside drastically changed the resulting image by changing the intensity of colours, creating shadows and therefore reduced the precision of applied algorithm.

3 Data manipulation

Upon starting the program, it opens a file explorer window, where user is asked to choose a directory containing the plant images using an intuitive and familiar interface. The program reads all images in a specified pathway (without checking the children nodes) and starts to perform an algorithm on each of them sequentially. Upon completion, a single text file with all generated data will be saved in the same location.

3.1 Finding the region of interest

To strike a balance between speed and accuracy of an algorithm, a 5472×3648 -pixel image is resized to a quarter of its original size (2736×1824 pixels). To reduce the operating area's size even further, the specific Region of Interest (ROI) is found. As a ROI for this particular task we have selected the part of the picture containing the soil inside a pot. Depending on the background of image, different techniques are used:

• For White Background Images (WBI), an image is converted from RGB to HSV and V channel subtracted from S channel Fig. 3.2 [9].

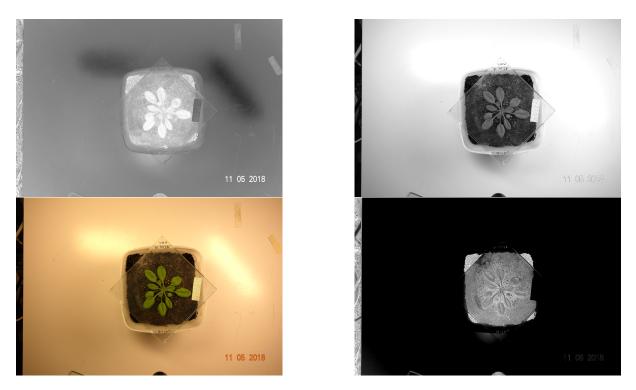


Figure 3.1: Used data (from top left to bottom right): S channel, V channel, original, result of subtraction.

• For Black Background Images(BBI), the Blue channel alone is extracted. Fig. 3.2



Figure 3.2: Used data: original (left), Blue channel (right).

Later, a threshold with the 50^{th} percentile is applied to the resulting pictures of both backgrounds. An acquired result (subtraction or Blue channel, respectively) is transformed into a binary mask Fig. 3.3. This mask is then processed with morphological operators. For WBI, mostly **closing** is used to remove small black regions Fig. 3.4 [2]. For BBI, mostly **opening** is used to remove any small white particles Fig. 3.4 [3].

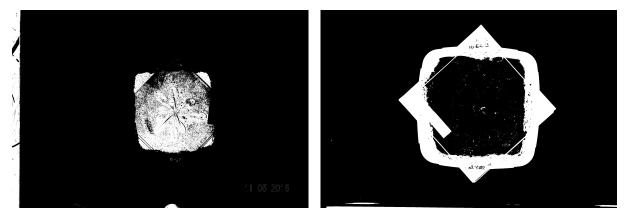


Figure 3.3: Thresholded results of subtraction and Blue channel.

Using OpenCV built-in *findContours* function all contours of the black and white regions of the picture are acquired. For the WBI, the biggest region is then selected, while for the BBI the second-largest is picked (which will represent the soil inside the pot; the biggest one being the area outside of the pot). As the next, this region is extended to include the boundaries of the pot itself and the glass piece as sometimes the reference mark might be located there. For further steps of the algorithm this smaller region of original image is used. This step saves a noticeable amount of time required for further processing and computation. An approximate size of such region is 1000×1000 pixels, which, in short, contains the pot with a plant.

3.2 Reference calculation

Objects in the digital image have their sizes represented in pixels. To find real area measurements in metric units, a reference tool with a known area is used. Later, using the proportion

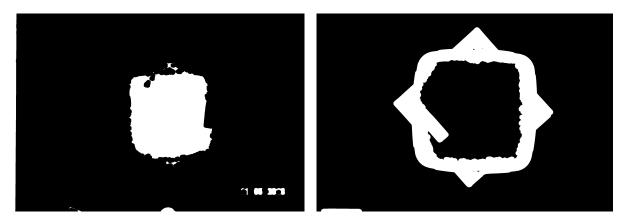


Figure 3.4: Closing results of subtraction (WBI) and Blue channel thresholded (BBI).

between segmented reference digital and actual sizes, an area of the plant can be calculated. The reference object is always placed on the same level as plant, usually on top of the glass plate. It ensures that the plant and the reference paper have the same relative sizes (the difference between items' sizes based on their distance from the absolute centre of the picture are negligible on that scale). As a reference we have used a small piece of paper. Yellowish and bluish pieces of millimetre paper used in this capacity always have a specific size of 3×1 centimetre, resulting in three square centimetres.

The initial algorithm for detection of that reference object was based on spotting a repetitive grid pattern in the picture. Processing image with Fourier Transform turned out to be a time consuming process with low precision. Therefore, a new type of reference object was chosen, namely a blue plastic piece. Its benefits are perceptible colour and shape. It is easily found by its colour and its area easily calculated Fig. 3.5. The program checks for the blue reference tool first. In case it was not located in the picture, the (less efficient) search for a millimetre paper is launched. In both cases, the area of the reference item is calculated and number of pixels saved for future calculations. The idea of subtraction different channels to highlight needed regions also used for blue reference paper.

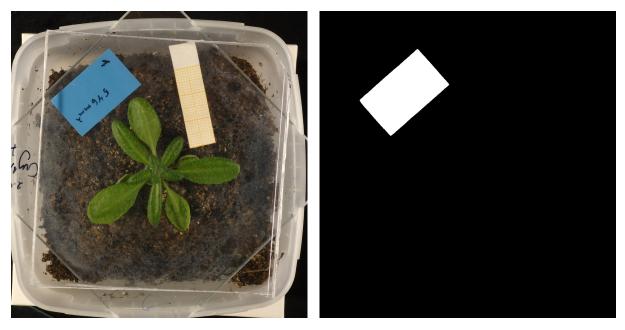


Figure 3.5: Cropped plant pot and Blue reference object mask

The approach used to find reference object uses Blue and Red channels of the image. Subtracting Red channel from the Blue one of the same image removes most of the irrelevant data and somewhat highlights the required area needed Fig. 3.6. To obtain the final boundary, the result of the previous step is thresholded, creating a binary image Fig. 3.5. , from which we calculate the number of white pixels to get an digital area of a reference object.

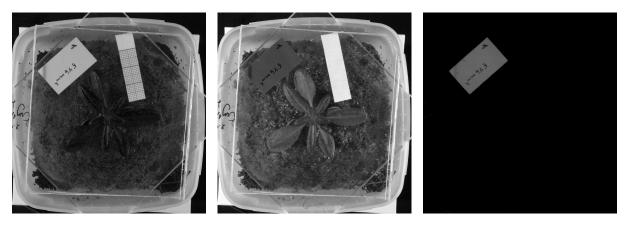


Figure 3.6: Blue channel, Red channel and result of subtraction.

3.3 Leaf segmentation

Input for that step is soil area with plant. It was obtained by applying mask from the first step on cropped pot Fig. 3.7. In case of WBI only white region is used from original image. In case of BBI only black area inside highlighted perimeter-of-the-pot area is used from original image.



Figure 3.7: Selected regions from WBI and BBI.

3.3.1 Part one

Two main challenges for a successful leaf segmentation operation are finding the leaves' boundaries and filtering the noise from soil particles. To crop an image even more and show plant from closer up for better representation, the colour space is changed and new area selected. A copy of original RGB format image is converted into a LAB colour space [11]. The result is an image also represented in three channels: L, A and B. Subtracting B channel from the A highlights plant areas Fig. 3.8. Based on new image program selects a new smaller region for next step.





Figure 3.8: Normalized A and B channels subtraction, cropped plant.

3.3.2 Part two

Splitting the RGB image into three separate channels makes it clearly visible that Green channel has easily distinguishable leaves alongside some noise. Blue channel has the outlines of leaves and noise in same spots as the Green channel. Therefore, subtracting B channel from G gives a good image for Otsu's thresholding technique [10]. Despite that, the acquired black and white mask might still have some noise in it. Finding all contours on the mask allows to remove all objects smaller than a specified number of pixels by turning them black. Final result of this operation is used for many of the next steps later in the execution. Number of white pixels in the plant mask is calculated and stored in the system Fig. 3.9.

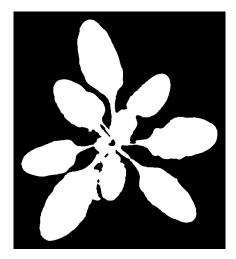


Figure 3.9: Main plant mask.

3.4 Visualization

In the last step, all information is collected together, processed and displayed in a single output window. First of all, the window is divided into three sections: on the left, there are highlighted plant leaves bounded with a solid line; on the right, there are numerical results of calculations and the initial image of a plant in the pot Fig. 3.10 and Fig. 3.11.

Based on a plant mask found in the previous step, the contours are found and added to the final output image to mark the bound between the leaves and the ground. The main window of a program shows the result of segmentation as well as the original image without stretching or change of perspective. Useful information in the corner tells user the following: name of the image file, estimated area of the plant in square centimetres, number of pixels for plant and reference object. Additional drawings allow the operator to understand all results visually.



Figure 3.10: Output window, example 1

3.5 Operator improvements

Operator has been given a possibility to add and remove selected regions of a plant area (detected by the machine) using a mouse. Drawing onto the processed image with green brush will add to the coloured area representing the leaves and switching to the red brush allows to remove parts of that area. Each change is added to the image and plant area is recalculated. The software supports different keyboard inputs:

- **H** button invokes a new window with detailed instructions for use. It explains how to use the brushes and lists all other possible commands.
- Escape button terminates the program at any time.
- Enter button allows manual input for reference paper area in case of inaccurate calculation (numerical value; measured in pixels).



Figure 3.11: Output window, example 2

- **F** button turns fast mode, where all images are processed without inspection. No perpicture results are shown and modifying the leaves' area is unavailable.
- **B** button removes the last area deletion or addition by the user.
- Space button saves all changes for the current file and continues to the next image.

4 Results

In total, 200 images were used for the development and calibration of the algorithm. Used method for finding ROI is a crucial step for all of the program calculations. Our implementation of it performs well and successfully removes a lot of the noise, allowing further steps in the execution process to work properly. Although it should be noted that it is very specifically tailored for images with plant in a white pot standing near the centre. During the testing phase, some different experimental approaches attempted have led to the introduction of a new reference object, which boosted the performance of program. It reduced both time used for calculation and the computational load on a running computer.

A couple subsets of images were provided with some additional data to them. The information included calculations of plant surface areas acquired manually by lab workers. By running the developed program on the same sets we were able to create comparable set of values. Accuracy was measured for images done on white background with an old type reference paper and for images done on black background with a new reference object together. The accuracy of an automated system is 93.55%, having the acceptance radius as $\mu \pm \sigma$ of distribution. We believe that the main difference with manual calculations done by people is that those included overlapped regions of leaves, which our software is unable to detect in its current iteration.

For one set of images there was a possibility to measure accuracy compared to cut leaves of same plant Fig 4.1. First, images of untouched plants were taken, then all leaves were cut and put on a glass plate. Cut leaves were flattened, so they had no curves or bending edges. All leaves were separated, so there are no overlapping regions. In that case accuracy of an automated system is 83.33%, having the acceptance radius as $\mu \pm \sigma$ of distribution, which confirmed our assumption about partially or wholly hidden leaves.

Mean	2.12
Variance	8.14
STD	2.85
Error %	93.55

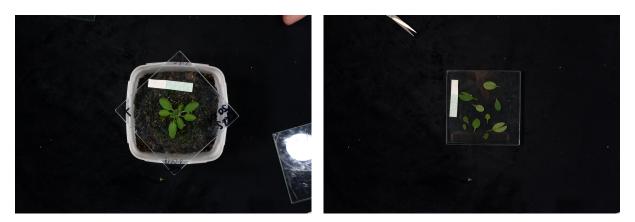


Figure 4.1: Untouched plant, cut leaves.

5 Conclusion and future work

A new method was developed for automatic detection of soil in a pot and the calculation of the plant surface. Advantages of different colour spaces were studied and used. This result shows the power of computer vision in automation of information extraction process. A desktop application was created to solve specific task and it will be improved further.

The presented method was tested on different sets of images, showing good results and promising the immediate benefits to lab workers. The achieved accuracy of work 93.55% makes the program a viable alternative for hard manual work. Generated under operator observation output is encouraging.

Different stages of program can be further improved to expand possible use cases. The prediction system can be incorporated within the main algorithm to take into account the overlapped regions of leaves. The extracted plant region can be used to find number of leaves or detect illnesses.

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Appendix

Area(cm2)	Calculated	Difference	%Error	<3.55	<4.97
10.86474	10.828	0.03674	0.339306	1	1
9.17895	9.11	0.06895	0.756861	1	1
18.21424	18.188	0.02624	0.144271	1	1
11.84475	11.952	0.10725	0.897339	1	1
9.33931	9.135	0.20431	2.236563	1	1
16.60635	16	0.60635	3.789688	0	1
13.30654	16.67	3.36346	20.17672	0	0
12.76732	12.331	0.43632	3.538399	1	1
12.01757	11.737	0.28057	2.390475	1	1
12.06603	11.996	0.07003	0.583778	1	1
12.16989	12.314	0.14411	1.170294	1	1
13.4923	13.447	0.0453	0.336878	1	1
11.29325	11.147	0.14625	1.312012	1	1
9.87604	9.79	0.08604	0.878856	1	1
8.97149	8.949	0.02249	0.251313	1	1
11.28438	10.989	0.29538	2.687961	1	1
11.67681	11.678	0.00119	0.01019	1	1
7.26941	7.146	0.12341	1.72698	1	1
5.52325	5.433	0.09025	1.661145	1	1
7.89364	7.694	0.19964	2.594749	1	1
6.31971	6.266	0.05371	0.857166	1	1
12.42081	12.064	0.35681	2.957643	1	1
12.34526	12.182	0.16326	1.340174	1	1
8.36524	8.352	0.01324	0.158525	1	1
10.65191	10.597	0.05491	0.518166	1	1
10.11213	9.862	0.25013	2.536301	1	1
14.24239	13.72	0.52239	3.807507	0	1
18.77238	17.837	0.93538	5.244043	0	0
22.85064	22.359	0.49164	2.198846	1	1
19.68701	19.638	0.04901	0.249567	1	1
12.51074	12.129	0.38174	3.147333	1	1
8.60942	8.93	0.32058	3.589922	0	1
15.00038	15.024	0.02362	0.157215	1	1
14.64219	14.132	0.51019	3.610175	0	1
8.33495	8.269	0.06595	0.797557	1	1
12.60653	12.766	0.15947	1.249178	1	1
13.79627	13.946	0.14973	1.073641	1	1
10.63483	10.652	0.01717	0.16119	1	1
	10.86474 9.17895 18.21424 11.84475 9.33931 16.60635 13.30654 12.76732 12.01757 12.06603 12.16989 13.4923 11.29325 9.87604 8.97149 11.28438 11.67681 7.26941 5.52325 7.89364 6.31971 12.42081 12.34526 8.36524 10.65191 10.11213 14.24239 18.77238 22.85064 19.68701 12.51074 8.60942 15.00038 14.64219 8.33495 12.60653 13.79627	10.86474 10.828 9.17895 9.11 18.21424 18.188 11.84475 11.952 9.33931 9.135 16.60635 16 13.30654 16.67 12.76732 12.331 12.01757 11.737 12.06603 11.996 12.16989 12.314 13.4923 13.447 11.29325 11.147 9.87604 9.79 8.97149 8.949 11.28438 10.989 11.67681 11.678 7.26941 7.146 5.52325 5.433 7.89364 7.694 6.31971 6.266 12.42081 12.064 12.34526 12.182 8.36524 8.352 10.65191 10.597 10.11213 9.862 14.24239 13.72 18.77238 17.837 22.85064 22.359 19.68701 19.638 12.51074 12.129 8.60942 8.93 15.00038 15.024 14.64219 14.132 8.33495 8.269 12.60653 12.766 13.79627 13.946	10.86474 10.828 0.03674 9.17895 9.11 0.06895 18.21424 18.188 0.02624 11.84475 11.952 0.10725 9.33931 9.135 0.20431 16.60635 16 0.60635 13.30654 16.67 3.36346 12.76732 12.331 0.43632 12.01757 11.737 0.28057 12.06603 11.996 0.07003 12.16989 12.314 0.14411 13.4923 13.447 0.0453 11.29325 11.147 0.14625 9.87604 9.79 0.08604 8.97149 8.949 0.02249 11.28438 10.989 0.29538 11.67681 11.678 0.00119 7.26941 7.146 0.12341 5.52325 5.433 0.09025 7.89364 7.694 0.19964 6.31971 6.266 0.05371 12.42081 12.064 0.35681 12.34526 12.182 0.16326 8.36524 8.352 0.01324 10.65191 10.597 0.05491 10.11213 9.862 0.25013 14.24239 13.72 0.52239 18.77238 17.837 0.93538 22.85064 22.359 0.49164 19.638 0.04901 12.51074 12.129 0.38174 8.60942 8.93 0.32058 15.00038 15.024 0.02362	10.86474 10.828 0.03674 0.339306 9.17895 9.11 0.06895 0.756861 18.21424 18.188 0.02624 0.144271 11.84475 11.952 0.10725 0.897339 9.33931 9.135 0.20431 2.236563 16.60635 16 0.60635 3.789688 13.30654 16.67 3.36346 20.17672 12.76732 12.331 0.43632 3.538399 12.01757 11.737 0.28057 2.390475 12.06603 11.996 0.07003 0.583778 12.16989 12.314 0.14411 1.170294 13.4923 13.447 0.0453 0.336878 11.29325 11.147 0.14625 1.312012 9.87604 9.79 0.08604 0.878856 8.97149 8.949 0.02249 0.251313 11.28438 10.989 0.29538 2.687961 11.67681 11.678 0.00119 0.01019 7.26941 7.146 0.12341 1.72698 5.52325 5.433 0.09025 1.661145 7.89364 7.694 0.19964 2.594749 6.31971 6.266 0.05371 0.857166 12.42081 12.064 0.35681 2.957643 12.34526 12.182 0.16326 1.340174 8.36524 8.352 0.01324 0.158525 10.65191 10.597 0.52239 3.807507 18.7723	10.86474 10.828 0.03674 0.339306 1 9.17895 9.11 0.06895 0.756861 1 18.21424 18.188 0.02624 0.144271 1 11.84475 11.952 0.10725 0.897339 1 9.33931 9.135 0.20431 2.236563 1 16.60635 16 0.60635 3.789688 0 13.30654 16.67 3.36346 20.17672 0 12.76732 12.331 0.43632 3.538399 1 12.01757 11.737 0.28057 2.390475 1 12.06603 11.996 0.07003 0.583778 1 12.16989 12.314 0.14411 1.170294 1 13.4923 13.447 0.0453 0.336878 1 11.29325 11.147 0.14625 1.312012 1 9.87604 9.79 0.08604 0.878856 1 8.97149 8.949 0.02249 0.251313 1 11.28438 10.989 0.29538 2.687961 1 11.67681 11.678 0.0119 0.01019 1 7.26941 7.146 0.12341 1.72698 1 5.2325 5.433 0.09025 1.661145 1 7.89364 7.694 0.19964 2.594749 1 6.31971 6.266 0.05371 0.857166 1 12.42081 12.064 0.35681 2.957643 1

Imaga	Area(cm2)	Calculated	Difference	%Error	<3.55	<4.97
Image DSC09485.JPG	10.01126	9.924	0.08726	0.879283	< <i>3.33</i>	<4.97 1
DSC09485.JPG	13.97361	13.835	0.08720	1.001879	1	1
DSC09480.JPG DSC09487.JPG	8.59266	8.374	0.13861	2.611177	1	1
DSC09487.JPG DSC09488.JPG	8.39200 11.23281	8.374 11.416	0.21800	1.604678	1	1
					0	
DSC09489.JPG	12.31811	11.851	0.46711	3.941524	0	1
DSC09490.JPG	3.84824	4.151	0.30276	7.293664	-	0
DSC09491.JPG	5.80438	5.819	0.01462	0.251246	1	1
DSC09492.JPG	8.39319	8.288	0.10519	1.269184	1	1
DSC09493.JPG	4.52031	4.42	0.10031	2.269457	1	1
DSC09494.JPG	7.76068	7.501	0.25968	3.461938	1	1
DSC01679	12.301	12.701	0.400266	3.151452	1	1
DSC01680	12.906	13.156	0.249649	1.897602	1	1
DSC01681	10.159	10.069	0.090337	0.897179	1	1
DSC01682	10.841	10.826	0.01541	0.142345	1	1
DSC01683	12.314	12.434	0.120315	0.967626	1	1
DSC01684	10.811	10.720	0.091381	0.852435	1	1
DSC01685	10.974	11.080	0.105577	0.952864	1	1
DSC01697	9.100	8.907	0.192778	2.164344	1	1
DSC01698	8.847	8.850	0.002534	0.028632	1	1
DSC01699	12.124	12.037	0.087087	0.72349	1	1
DSC01700	12.027	11.140	0.887097	7.963171	0	0
DSC01701	17.765	17.204	0.561265	3.262412	1	1
DSC01702	9.888	9.652	0.235582	2.440762	1	1
DSC01703	10.420	10.385	0.035051	0.337519	1	1
					53	58
All img number	62		Mean	2.121029		
e			Variance	8.138893		
			STD	2.852874		
		%Error <mean +="" 2<="" std="" td=""><td>85.48</td><td></td><td></td></mean>		85.48		
		%Error <mean +="" std<="" td=""><td>93.55</td><td></td><td></td></mean>		93.55		
				10.00		

Image	Cut leaf(cm2)	program	Difference	%Error	<17.12	<34.24
DSC00682	6.496	6.064	0.432	7.124011	1	1
DSC00685	4.61	4.279	0.331	7.735452	1	1
DSC00687	7.769	7.509	0.26	3.462512	1	1
DSC00689	13.074	11.898	1.176	9.884014	1	1
DSC00692	4.489	3.906	0.583	14.92576	1	1
DSC00694	9.797	7.674	2.123	27.66484	0	1
DSC00696	8.042	8.3	0.258	3.108434	1	1
DSC00698	8.526	7.153	1.373	19.19474	0	1
DSC00700	14.385	13.318	1.067	8.011713	1	1
DSC00702	12.332	9.234	3.098	33.54992	0	1
DSC00704	11.848	7.817	4.031	51.5671	0	0
DSC00706	20.521	14.912	5.609	37.614	0	0
					7	10
all img num	12		mean	18.65354		
			var	243.1638		
			STD	15.59371		
		%Error <mean +="" 2<="" std="" td=""><td>58.33</td><td></td><td></td></mean>		58.33		
		%Error <mean +="" std<="" td=""><td>83.33</td><td></td><td></td></mean>		83.33		

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