Method for Measuring Leaf Area of Brassica Napus Using Image Analysis

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ABSTRACT

Leaf is an important part of plants. A rapid and accurate detection of plant leaf area is an important guidance to reasonable fertilizer application and accurate sprinkler irrigation. In order to solve the problem of large error and incomplete target region in segmenting leaves when people using Otus's threshold method, a method based on watershed algorithm was proposed to segment the leaves of Brassica napus. Firstly, the images of relevant crop leaves are collected by the digital camera on site. Then these images are preprocessed by Sobel operator and morphological operation. Thirdly, labeled images are segmented by watershed algorithm to get target images. Finally the leaf area is calculated by counting the number of pixels in target area. The experimental results show that this method can solve the problem of incomplete segmentation of the Otus's threshold method and effectively reduce the measurement error to less than 2.2%.

CCS CONCEPTS

• **Theory of computation**; • **Theory and algorithms for application domains**; • **Machine learning theory**;

KEYWORDS

Plant leaf area, Top-hat processing, Watershed algorithm, MATLAB 2020a

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1 INTRODUCTION

The photosynthesis, respiration and transpiration on leaves are closely related to the normal growth of plants. The size of the leaf affects the intensity of photosynthesis, respiration and transpiration, and has a significant impact on the nutritional status, growth, yield of plants and so on. So, rapid and accurate detection of plant leaf area is an important guidance for rational fertilizer application and accurate spraying, and it has important reference for accurately estimating insect damage and spraying correct types and reasonable amount of pesticides.

In 1992, Trooien opened the first research on the use of image processing techniques to obtain the leaf area of potatoes [1], collected leaf images from three mutually perpendicular directions, processed them separately to obtain the corresponding leaf area, and then synthesized these three leaf areas into the real leaf area. The result was similar to that obtained by using the leaf area meter. Habibur Rahman used the near-infrared images of plants under greenhouse conditions to calculate the leaf area of lettuce in the early stage [2]. Confalonieri R. used four methods to measure the leaf area of an isolated tree and compared their accuracy and efficiency [3]. Its results showed that the most accurate leaf area was obtained by using colour image processing. Based on the "the elliptical Hough transform" image algorithm, Demarez V. [4] and Gonsamo A. [5] designed an image processing method to estimate the leaf area of continuously growing vegetable seedlings. K. Hameed, D. Chai and A. Rassau proposed a class distribution-aware adaptive margins approach with cluster embedding for classifification of fruit and vegetables [6].

In China, scholars developed some leaf area measurement devices by combining software and hardware. Zhang Jianqin and others developed a leaf area measurement software system on the VC++6.0 platform by using machine vision technology [7], but the measurement algorithm of this system ignored the effects of leaf deformation and overlap. Zuo Xin used an improved Hough transform algorithm to correct the geometric distortions produced by the acquired images, and then calculated the leaf area [8]. Based on them, this paper proposes a method for calculating plant leaf area based on the Watershed algorithm. The purpose of this method is to solve the problem of incomplete target areas when segmenting with the Otus algorithm, to improve the integrity of plant leaves when segmenting, and to reduce errors. The Watershed algorithm is used to segment the image, which can accurately and quickly segment the plant leaves from the background, and provided the basis for subsequent calculations. To reduce errors, the image after pre-processing is subjected to image binarization and denoising. Finally, the area of the plant leaves is calculated by counting the pixel points in the target area.

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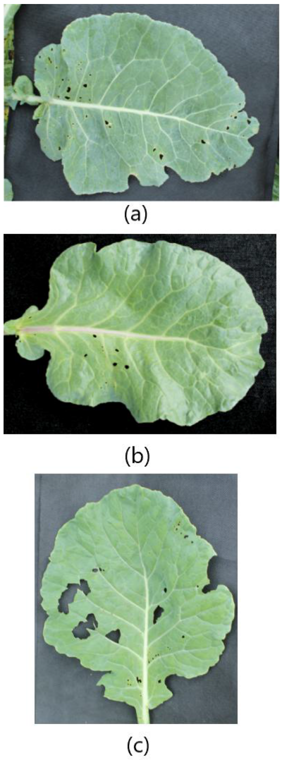


Figure 1: Partially Collected Leaf Images.

2 BACKGROUND METHODOLOGY AND MATERIALS

2.1 Image Acquisition

In the leaf analysis of the crop, the target area is obvious, and the background is simple. Less noise leaf image can improve the effect of image processing, and image segmentation and feature extraction can get twice the result with half the effort. This is why digital cameras or digital video cameras are often used when acquiring leaf images. The acquisition environment can be divided into indoor and outdoor acquisition. The indoor environment is stable and has less influencing factors. Controlling the light can get a clear leaf image. The natural environment is susceptible to external factors such as light, wind, dust, etc. The leaf images collected in vivo will also have the influence on the shooting angle. Therefore, most previous research by scholars brought leaf samples indoors for filming, and good research results have been achieved for pest and disease detection of crops, but this method cannot study the whole growth process of the leaves [9&10]. Therefore, the author used digital camera to collect leaf images in outdoor living body. All the images for the experiments in this paper were collected from the Wuhan Brassica napus experimental field at the Institute of Oilseed Crops Chinese Academy of Agricultural Sciences. Some of these images are shown in Figure 1

2.2 Image Pre-Processing

The image pre-processing process steps are:

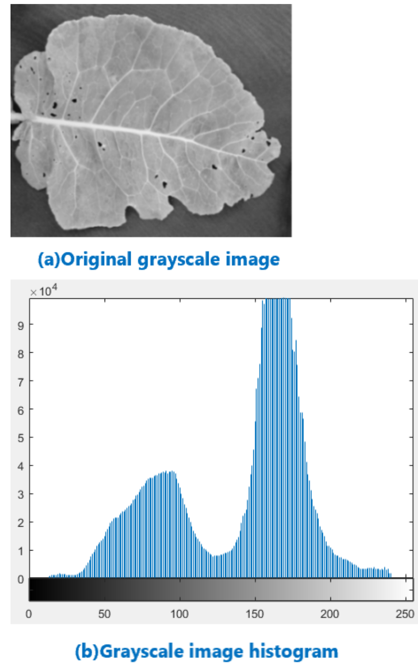


Figure 2: Histogram of A Greyscale Image.

- cutting the image, preserving the target region;
- converting the processed image to a greyscale image through MATLAB;
- processing the image by using the Sobel operator to highlight the image boundaries;
- highlighting the brighter parts of the contours around the original image through top-hat processing in morphological operations;
- segmenting the image through the watershed algorithm [11].

2.2.1 Image Greyscaling. The images of plant leaves captured by the digital camera are true colour images. All pixels in a color image are composed of R, G, and B three channels. In order to obtain more accurate edge gradient information and make the subsequent image segmentation more accurate, the captured true colour image needs to be greyed out first. Image greyscaling is the process of making the R, G and B components of colour equal [12]. In this research work, the author uses the weighted average method to process the image. The weighting coefficients for R, G and B are 0.229, 0.587 and 0.114 respectively [13]. The weighted average is calculated as follows:

$$Y(x, y) = 0.229R(x, y) + 0587G(x, y) + 0.114B(x, y) \quad (1)$$

Where Y(x, y) is the greyscale value of the colour image greyed out at point (x, y), R(x, y) denotes the red component of the image at point (x, y), G(x, y) denotes the green component of the image at point (x, y) and B(x, y) denotes the blue component of the image at point (x, y). Figure 2 shows the histogram of the greyscale image in Figure2(a), with the pixels in Figure 2 appearing most frequently at grey levels in the range of 150-200.

-1	0	+1
-2	0	+2
-1	0	+1

(a) Horizontal direction

+1	+2	+1
0	0	0
-1	-2	-1

(b) Vertical direction

Figure 3: Sobel Convolution Factor.

2.2.2 Sobel Operator Sharpening and Top-Hat Processing. Image sharpening highlights the image boundaries and enhances the contrast of the image's grey values to make the image clearer. Here the auther chose the Sobel operator to transform the image. Technically, the Sobel operator is a discrete difference operator, which is usually used to calculate the grey scale approximation of the image luminance function and consists of two sets of 3 x 3 matrices. The horizontal and vertical convolution factors of the Sobel operator are shown in Figure 3. Figure 3 corresponds to the Sobel convolution factor in the horizontal direction and Figure 3 corresponds to the Sobel convolution factor in the vertical direction. Using the above two convolution factors respectively to do a planar convolution of the target image, the approximate value of horizontal and vertical brigtness difference at any point can be obtained.

According to the 3×3 template of the Sobel operator, the following formula for calculating the image grey value of this operator can be obtained.

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * A \tag{2}$$

$$G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * A \tag{3}$$

Where, $G_x$denotes the grey value of the image in the horizontal direction, $G_y$denotes the grey value of the image in the vertical direction, and A is the original image. On this basis the greyscale values of any point on the image in the horizontal direction and the vertical direction are combined by formula (4), and the greyscale value of the point can be obtained as:

$$G = \sqrt{{G_x}^2 + {G_y}^2} \tag{4}$$

For efficiency, an unsquared approximation is usually used as the greyscale value, as shown in equation 5).

$$G \approx |Gx| + |Gy| \tag{5}$$

because the image has an impact on segmentation accuracy when acquired under uneven lighting, the author used the Top-hat operation to process the image. Using equation 6) to subtract the original image A from its open operation image, we can highlight the brighter areas around the original image contour.

$$T_{hat} = A - \left(A^{\circ} b\right) \tag{6}$$

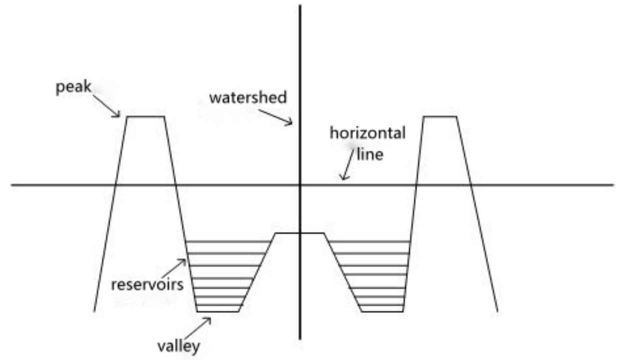


Figure 4: Watershed Bottom-Up Model.

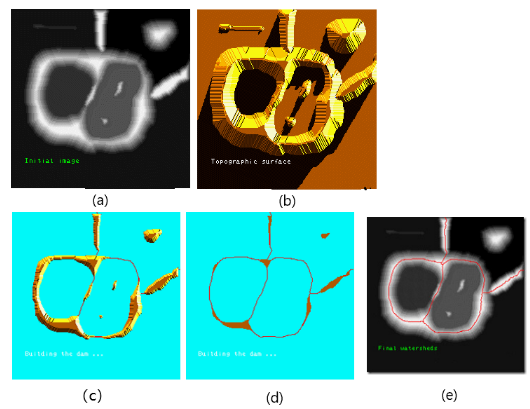


Figure 5: Watershed Algorithm Process.

3 IMAGE SEGMENTATION AND LEAF AREA CALCULATION

3.1 Watershed Algorithm Segmentation

There are three main methods of image segmentation: threshold-based segmentation, region-based segmentation and edge-based segmentation [12]. In this research work, the image is treated as an undulating topographic map and segmented by using a region-based watershed approach. Segmentation is roughly a bottom-up submersion process, as shown in Figure 4. Water is injected from the bottom of the valley . When water floods the cistern, it meets the water from nearby cisterns, and thus converges, builds a dam just as they are about to converge. This dam is the watershed. The segmentation experiments are simulated by Matlab2020a.

The basic idea of the Watershed algorithm is that after the original image is greyed out, the grey value of each pixel point in the grey image represents the elevation of that point, each local minimum called the valley floor, and the area around its affected called the reservoir [9]. A schematic diagram is shown in Figure 5. Figure 5(a) is a greyscale image, and Figure5(b) is a topographic map of it. Figure 5(c) and Figure5(d) represent the process of water immersion, and the final segmentation is shown in Figure5(e).

The Watershed Algorithm model is actually an iterative process. In order to describe the process, there are the following definitions.

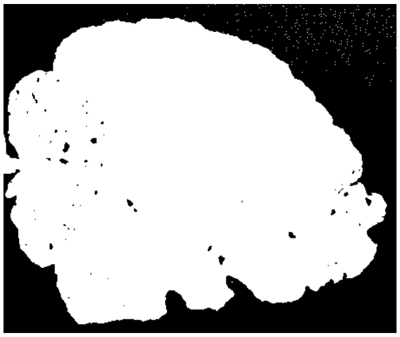


Figure 6: Binary Image After Segmentation.

Figure 7: Contour Edge Image.

Definition 1: The set of pixels h in an image G with a threshold of

$$T_h = \{p \in D \mid G(p) \leq h\} \tag{7}$$

In equation 7), G is the image; p is the pixel in the image G; D is the set of all pixels in the image G.

Definition 2: The set of impact regions is given by

$$C_A(B_i, B) = \{p \in A \mid d_A(p, B_i) \ < \ d_A(p, B - B_i)\} \tag{8}$$

$$C_A(B) = \cup C_A(B_i, B), i = 1, 2, \ldots, k \tag{9}$$

In equation 8), B is the subset A. The $d_A(p, B_i)$ represents the shortest path from p to B_i.

Definition 3: The iterative process is described as

$$\begin{cases} X_{h_{min}} = T_{h_{min}}; \\ X_{h+1} = min_{h+1} \cup C_{T_{h+1}}(X_h), h \in [h_{min}, h_{max}]. \end{cases} \tag{10}$$

In equation 9), h denotes the region of image grey scale change; h_{min} and h_{max} denotes the minimum and maximum values of grey scale in image; X_h denotes the set of pixels when the grey scale value is h; min_{h+1} is the minimum value of the newly generated reservoir.

3.2 Contour Extraction

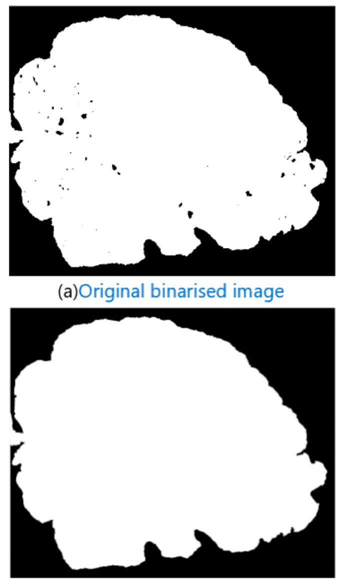
Using the function in MATLAB we can obtain the contour of the object in the binarised image, the formula is shown in (11), the "option" value is set to "noholes", only the outer boundary of the target leaf area is searched to building an edge image. This is shown in Figure 6 and Figure 7

$$B = bwboundaries(bw, conn, options) \tag{11}$$

3.3 Filling of Leaf Images

Filling of the image means filling the area of the image and the worm holes. As the insect holes on the infested leaves can affect the calculation of the plant leaf area, the image is filled before the calculation is carried out.

The Flood Fill function in MATLAB is used to fill the background area of the original binary image from Seed Point, set the starting pixels to Point (0, 0) and fill colour to white, i.e. set the pixel value to 1. When the background area of the original binary image is completely filled, the whole image becomes white, except for the inner points of the original image.



(a)Original binarised image

(b) Filled binarised image

Figure 8: Process of Filling Image.

The filled image is inverted and its size is cut to the size of the original image. Now the image is black except for the area that needs to be filled in the interior of the leaf, which is white. The original binary image is then merged with the new image after the inverse operation, then we obtain a binary image with all the insect holes filled [13]. The Flood Fill function was used to process the binary image in this paper, and the fill result is shown in Figure 8

3.4 Leaf Area Calculation

The area is calculated by counting the number of pixels in the target area of the image. As shown in Figure 8(b), the calculated target area is the white part of the image, with a pixel value of 1. The other parts have a pixel value of 0. Each pixel is discrete, and the area calculation formula is equation 12).

$$leafareal = \sum_{i=1}^{M} \sum_{j=1}^{N} f(x, y) \tag{12}$$

Table 1: Experimental Data for Leaf Image Segmentation of Brassica Napus

	Manual methods		Method adopted in the experiment		Results
	Leaf	Background	Leaf	Background	Error rate
1	4111900	7650	4103900	32028	0.79%
2	3813800	15821	3799400	14246	0.42%
3	4026400	11665	4021600	13994	0.18%
4	4056978	12296	4050000	13581	0.20%
5	3904700	13731	3898700	15908	0.21%
6	3474100	10053	3468100	10606	0.19%
7	3641100	10843	3641800	97673	2.20%
8	3722400	9667	3710400	16957	0.52%
9	3623400	13391	3602400	9566	0.69%
10	3159200	14988	3158200	30427	0.52%

In equation 12), f(x,y) is a binary image of size M x N.

4 ANALYSIS AND COMPARISON OF TEST RESULTS

4.1 Testing the Accuracy of the Segmentation Method

To test the accuracy of the segmentation method which based on the watershed algorithm, ten leaf images were randomly selected. The leaf pixel values and image background pixel values segmented by this method are compared with those by manual method respetivey. The manual method uses professional image processing software to key out the images of the target area and place them in a new black background image. The pixel numbers of the leaf images and background images by each method were recorded, and the data is shown in Table 1

The pixel value of the leaf region obtained by this experimental method were compared with those obtained by the manual method. The error rate of image segmentation was calculated by equation 13).

$$rate = \frac{|S_{02} - S_{01}|}{S_{01}} \times 100\% \tag{13}$$

In equation 13), $S_{01}$is the pixel value of rape's leaf region obtained by the manual method calculation, and S_{02} is the pixel value of leaf area calculated based on the watershed algorithm. From the calculations, the maximum error of the method used in this experiment is no more than 2.2%. A comparison of the data measured by the manual method and this experimental method are shown in Figure 9 and 10 respectively.

It can be seen from Table 1 that the maximum error rate of this experiment is 2.20%, which indicating that the method used in this experiment can meet the needs of daily experimental measurements. Five randomly selected Brassica napus's leaves were subjected to image segmentation. The comparison pictures between the original and segmented images is shown in Figure 11

The results from both Table 1 and Figure 9-11 show that in the segmented images based on the Watershed Algorithm segmentation method, the leaf region of Brassica napus's is relatively complete, the noise in the background is relatively small, and the segmentation accuracy is relatively high. Therefore, the pixel values of the target region can be calculated more accurately, so that the calculation value of leaf area is accurate.

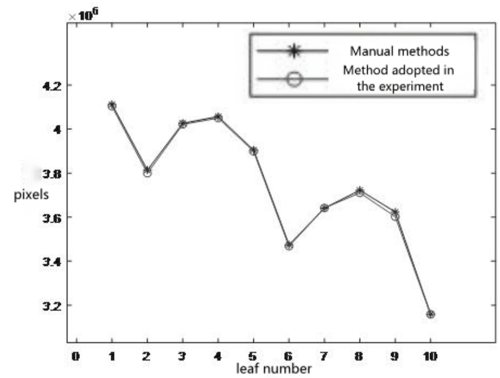


Figure 9: Comparison of Blade Pixels.

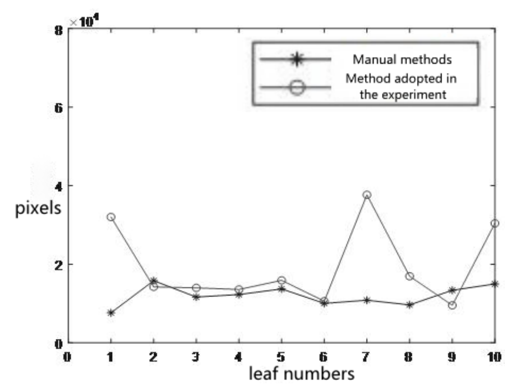


Figure 10: Comparison of Background Pixels.

5 CONCLUSION

In this study, the author used the watershed algorithm to segment the image of Brassica napus's leafs, and used the Sobel operator and top-hat processing to detect the edges of the original image and

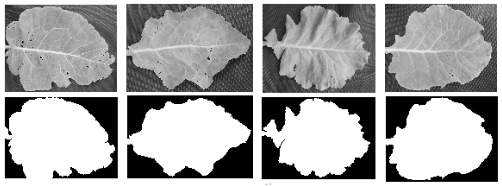


Figure 11: Comparison between the Original Image of the Blade and the Segmented Image.

highlight the brighter parts of the border. The results of this study were compared with the manual method results. The experimental results showed that the method used in this research work could reduce the measurement error of Brassica napus leaf area to no more than 2.2%, greatly improve the accuracy of measuring Brassica napus leaf area. It also provided a foundation for the team's future research on crop phenotyping based on machine learning and image processing.

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