Algorithm for extracting contours of agricultural crops images

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Abstract. Currently, identification of crop diseases and their prevention is one of the main problems in the field of agriculture. Conventional visual inspection is a time and money consuming process for farms. Therefore, images taken by unmanned aerial devices or satellites are used to assess the condition of crops, control them and identify diseases. In particular, when identifying crop diseases, it is necessary to first solve the problem of automatic recognition of their type through the image of crops. Usually contour separation algorithms are widely used in the segmentation of objects in the image. This work is aimed at solving the problem of separating the contour of the object, in which algorithms are formed based on Canny, Sobel and Robinson filters, which are considered to be popular and classical methods of contour separation, and their various combinations. In the computational experiments, a set of contour images, whose contours were separated by an expert, was used. Evaluation was performed by comparing the image obtained by applying the combination of filters to the original image and the corresponding contour image pixels separated by an expert. The proposed approach has been tested on a set of plant leaf images and shown to be effective.

1 Introduction

The type and volume of products grown in agriculture is increasing day by day. Agricultural products are one of the important parameters determining the economic development of the country. In the cultivation of agricultural products, farmers are entrusted with a highly responsible task, such as complete and accurate monitoring of the condition of the crops. In many countries, large areas of land are set aside for agricultural activities, and farmers spend a lot of time and money on monitoring the crops on these fields. In addition, one of the major problems faced by farmers in their work is the detection and prevention of crop diseases. Crop diseases hinder the quality development of agricultural products [1]. According to statistics, crop diseases cause the world's food to decrease by 40% every year. Expert visual inspection, which is known as the traditional method of detecting diseases in crops, is not up

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to the demand during the production process. Because this approach requires a lot of work and time, the expert is often prone to various errors. Therefore, it is necessary to develop an automated approach to the detection of diseases in crops. For this, the use of drones or satellite images is recognized as the most optimal solution today.

In order to identify crop diseases, it is necessary to first solve the problem of automatic recognition of plant species by plant leaves. In crop monitoring, images captured by special equipment provide important information about crops. However, when classifying plant leaves, instead of using all the information in the image, identifying an object in the image and then using its information about it increases the classification speed. Images taken directly from imaging devices may not provide automatic plant species recognition. Because the low quality of the image leads to a decrease in the recognition accuracy. This requires image processing.

One of the most important steps to recognize an object in an image is the segmentation step. The widely used methods for image segmentation are contour-based methods [2]. A contour can be taken as a border separating two regions of the image. Contour separation significantly reduces the amount of data to be processed, limiting invalid or low-value data and allowing for the most important information about the object. Contour-based information is widely used in object detection.

It depends on the fact that the contours of the image objects are clearly and completely obtained without various noises and distortions, as well as the contrast is at a normal level. Too much noise creates false contours [3]. Insufficient contrast prevents contours from being clearly and completely captured. Pre-processing is done to eliminate such problems.

In this research, Canny, Sobel and Robinson filters, which are popular and classic methods of contour separation, and their combinations in various combinations are studied and the effectiveness of the proposed approach is shown based on computational experiments.

2 Literature analysis

Currently, there are many approaches to the detection of contours of image objects. Examples of these are classic gradient [4], anisotropic filter [5], active contour based [6,7], machine learning based [8,9], fuzzy set based [10,11] and statistical algorithms [12,13].

Gradient-based algorithms are divided into two categories based on the use of first- and second-order derivatives. As an example of the methods based on the first-order particular derivative Orhei, Kayalli, Scharr, Prewitt and Roberts methods can be cited. However, these methods are rarely used in practice due to their sensitivity to noise. In the LOG (Laplacian of Gaussian) operator, which is based on the second-order derivative, a Gaussian filter is used first, and then the Laplacian operator.

The table below presents an analysis of filters that are widely used in object contour detection.

Table 1. Analysis of filters used in object contour detection.

№	Title of article	Year	Filters	Result	Measure, indicator	Dataset name
1	Comparison of Various Edge Detection Techniques [14]	2016	Canny, Sobel, Roberts, Prewitt, Morphological method	Sobel for outline, Morphological for face, Canny or Sobel for low resolution and time	Time, subjective	High and low resolution, face images, glass, wood images

2	A Comprehensive Analysis of Image Detection Techniques [15]	2017	Prewitt, Sobel, Canny, Roberts, LOG	Canny is good for noise, Sobel is good for object only	PSNR, MSE	Sunflower and Face image, 2 images
3	Relative Performance Analysis of Edge Detection Techniques in Iris Recognition System [16]	2018	Sobel, Prewitt, Canny	Canny is good for a noisy image	MSE, PSNR, Average difference (AD), Threshold value, Accuracy measure	1 iris image
4	About Edge Detection in Digital Images [17]	2018	Prewitt, Sobel, Robinson, Kirsch, Laplacian 4 connected, Laplacian 8 connected, Fractional derivatives	On 3 criteria, Canny is good	C_A, C_W, C_E, C_R, FOM	Image of Lena, 2 images from BSDS database
5	Consideration of Canny Edge Detection for Eye Redness Image Processing: A Review [18]	2019	Canny Edge detection method	Canny is the best at segmentation	Visual	Red eye images
6	Edge Detection Methods [19]	2020	Sobel, Prewitt, Roberts, Canny, LOG	Canny is less sensitive to noise	Visual	Fingerprint, butterfly image
7	Quality Assessment Methods to Evaluate the Performance of Edge Detection Algorithms for Digital Image: A Systematic Literature Review [2]	2021	Canny, Sobel, Prewitt	Canny, Sobel are the most popular methods	RMSE, MSE, PSNR, SNR, FOM	BSDS500, Pascal VOC2012

Canny method has been evaluated as an effective method in many literatures, which reduces the noise in the image before the contours are extracted. This method provides low errors and accurate localization. Sobel and Robinson methods are effective in determining the outer contour of the object. Based on the analysis of the literature and a large number of experiments Sobel, Canny and Robinson filters were selected as the basis in this research work.

3 Image processing

An image is a collection of pixels, which is expressed in matrix form as follows:

$$T = \begin{pmatrix} t_{11} & t_{12} & \dots & t_{1m} \\ t_{21} & t_{22} & \dots & t_{2m} \\ \dots & \dots & \dots & \dots \\ t_{n1} & t_{n2} & \dots & t_{nm} \end{pmatrix} \tag{1}$$

where $t_{ij}-$ is the brightness value of the pixel at position (i, j) of the image, $n-$is the height of the image, $m-$is the width of the image.

T image processing is carried out in the following steps:

1) Image acquisition;
2) Image pre-processing:
   a) contrast enhancement;
   b) noise reduction;
3) Contour separation, thinning, filling;
4) Segmentation;
5) Recognition;

In the first step, a digital image is taken using special imaging equipment.

In the second step, the image is pre-processed, that is, the image quality is evaluated using non-reference methods. Based on the value of the quality indicator, the contrast of the image is increased, and in the presence of noise, they are reduced.

a) Image contrast evaluation criteria and contrast enhancement methods have been developed by many researchers. Among the evaluation criteria, the GCF (global contrast factor) indicator is used in the work because it evaluates the color image contrast more accurately than other indicators. From the contrast enhancement methods, $HE-$ histogram equalization and $CS-$ contrast stretching methods were selected based on experience and research [20]. In this case, GCF indicator and image contrast enhancement methods were used, and the following recommendation was developed:

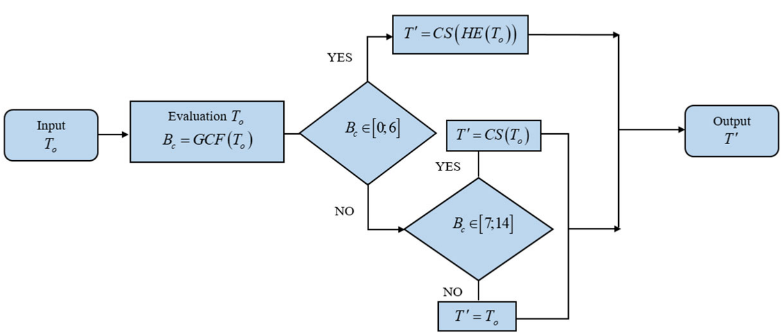

Fig. 1. A proposed approach to increase image contrast.

b) Random noises are added to the image due to various factors during the image acquisition and transmission processes. Among the noises, Gaussian, Poisson and salt and pepper noises are the most common in the image. To date, no specific approach has been developed to eliminate these noises when they are mixed in the image. Based on the analysis of existing papers on noise reduction, the BIQI criterion for image evaluation and the BM3D filter for Gaussian noise, TV for Poisson noise, and Median filter for salt-pepper noise were selected as the optimal filters for each type of noise reduction [21]. Based on the obtained effective filters, the hybrid filter $F-$ (BM3D+Poisson+Median) was used to reduce mixed noise. The approach proposed by the authors to eliminate mixed noise is shown in the figure below.

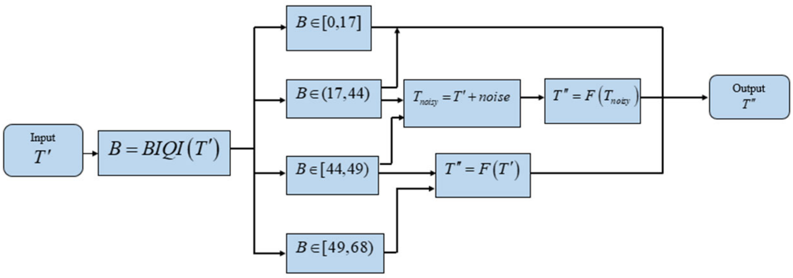

Fig. 2. Mixed denoising approach.

Step 3 is the most important, where contouring, thinning and filling are done. This is cited in the literature as the first step in object detection [22].

Based on literature analysis Sobel, Canny and Robinson filters were obtained for object contour detection. Applying these filters to an image is done as follows:

Sobel filter. In the Sobel filter, the brightness gradient and magnitude of $mag(\nabla T)$ are calculated for each point of the image [23].

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{2}$$

$$\frac{\partial T}{\partial x} = S_x \otimes T \; ; \quad \frac{\partial T}{\partial y} = S_y \otimes T \tag{3}$$

$$\nabla T = \left[\frac{\partial T}{\partial x}; \frac{\partial T}{\partial y} \right] \tag{4}$$

Robinson filter. The Robinson filter uses the following 8 masks.

$$\begin{gathered} N = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}, NE = \begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix} \\ E = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, NW = \begin{bmatrix} 2 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -2 \end{bmatrix} \\ W = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}, S = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \\ SW = \begin{bmatrix} 0 & -1 & -2 \\ 1 & 0 & -1 \\ 2 & 1 & 0 \end{bmatrix}, SE = \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix} \end{gathered} \tag{5}$$

The gradient magnitude is defined as the maximum value obtained by applying all 8 masks to a pixel neighborhood. This filter increases the accuracy of the gradient magnitude.

Canny filter. In the Canny method, the Gaussian method is first used to suppress the image noise. The magnitude and direction of the gradient are then calculated using the Sobel or Prewitt operators. Local maximums along the gradient direction are identified and the rest are suppressed, false edges are minimized.

The process after defining the contour is the thinning and filling of the contour. Contour thinning is a morphological operation aimed at reducing the width of the contour of an object while preserving its main topological features. Contour filling is the process of expanding the contour to make the contour of the object into a closed region [24]. Doing these steps makes it easier to analyze the object as a whole.

In step 4, segmentation is performed. Segmentation is the technique of dividing a digital image into different subgroups called image segments [24]. The output of the image segmentation algorithm can be provided as input to higher-level processing tasks.

The 5th step is the final stage, in which the features of the separated object are formed as a result of segmentation and recognition is performed based on these references [25-28].

4 Methods

The object contour detection filters used in this research work are defined as follows:

$$u_1 - \text{Sobel},\ u_2 - \text{Canny},\ u_3 - \text{Robinson}$$

Applying filters to T_o original image results in T_{u_i} contour images, i.e.:

$$T_{u_1} = u_1\left(T_o\right),\ T_{u_2} = u_2\left(T_o\right),\ T_{u_3} = u_3\left(T_o\right) \tag{6}$$

When evaluating the effectiveness of the received filters, the T_o contour corresponding to the original image T_k is separated by an expert and the pixels of T_{u_i} images resulting from the application of filters are checked according to the criterion B_i , $i = \overline{1,3}$. The following formula is used to calculate the values of criterion B_i :

$$B\left(T_k, T_{u_i}\right) = \frac{\left|T_k \cap T_{u_i}\right|}{\left|T_k\right|} \cdot 100\% \tag{7}$$

$\left|T_k\right| -$ is the total number of pixels in the contour image, $\left|T_k \cap T_{u_i}\right| -$ is the number of pixels at the intersection of T_k and T_{u_i} images.

$$B\left(T_k, T_{u_i}\right) \sim 100\% \tag{8}$$

The closer the value of $B\left(T_k, T_{u_i}\right)$ is to 100, the more effective the filter is.

$$u_{opt}^1 \in \max_i \left\{B_i\right\}, i = \overline{1,3} \tag{9}$$

Pairwise combinations of filters taken separately above in different combinations are checked:

$$u_{12} = u_1\left(T_o\right) \cup u_2\left(T_o\right),\quad u_{13} = u_1\left(T_o\right) \cup u_3\left(T_o\right),\quad u_{23} = u_2\left(T_o\right) \cup u_3\left(T_o\right) \tag{10}$$

$$T_{u_{12}} = T_{u_1} \cup T_{u_2}\ ,\ T_{u_{13}} = T_{u_1} \cup T_{u_3}\ ,\ T_{u_{23}} = T_{u_2} \cup T_{u_3} \tag{11}$$

Determining the effective one among these pairs of filters is done as follows:

$$u_{opt}^{pair} \in \max\left\{B\left(T_k, T_{u_{12}}\right), B\left(T_k, T_{u_{13}}\right), B\left(T_k, T_{u_{23}}\right)\right\} \tag{12}$$

The 3 filter combinations selected above are applied to the image as follows.

$$u_{123} = u_1\left(T_o\right) \cup u_2\left(T_o\right) \cup u_3\left(T_o\right) \tag{13}$$

$$T_{u_{123}} = T_{u_1} \cup T_{u_2} \cup T_{u_3} \tag{14}$$

The most effective filter is defined as:

$$u_{opt} \in \max\left\{u_{opt}^{1}, u_{opt}^{pair}, u_{123}\right\} \tag{15}$$

5 Computational experience and results

In the computational experiment, 100 images were obtained for the sample from the BSDS500 set of expertly contoured images. Examples of images created by applying contour detection filters to a set of images are shown in the figure below.

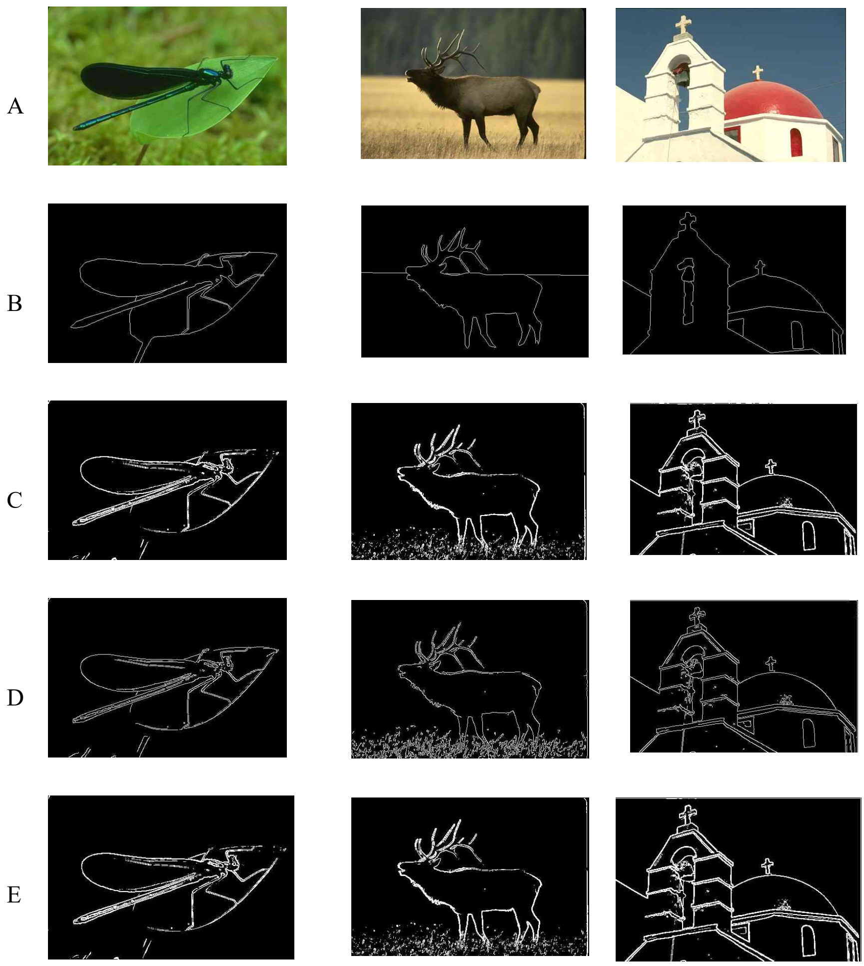

Fig. 3. A) Original image, B) Groundtruth image, C) $u_1 -$ Sobel filter, D) $u_2 -$ Canny filter, E) $u_3 -$ result of applying the Robinson filter.

The results of applying filters u_1, u_2, u_3 for 100 images were evaluated according to the formula (7) and the optimal filter was determined by the voting method. That is, the filter with the most votes was taken as the most effective filter:

$$|u_1| = 28\ ,\ |u_2| = 2\ ,\ |u_3| = 70$$

Among the separately obtained filters, u_3 -Robinson filter (7) was found to be the most optimal in terms of evaluation:

$$u^1_{opt} \sim u_3$$

Below are the results of the test of pairs of filters in different combinations taken separately (Figure 4).

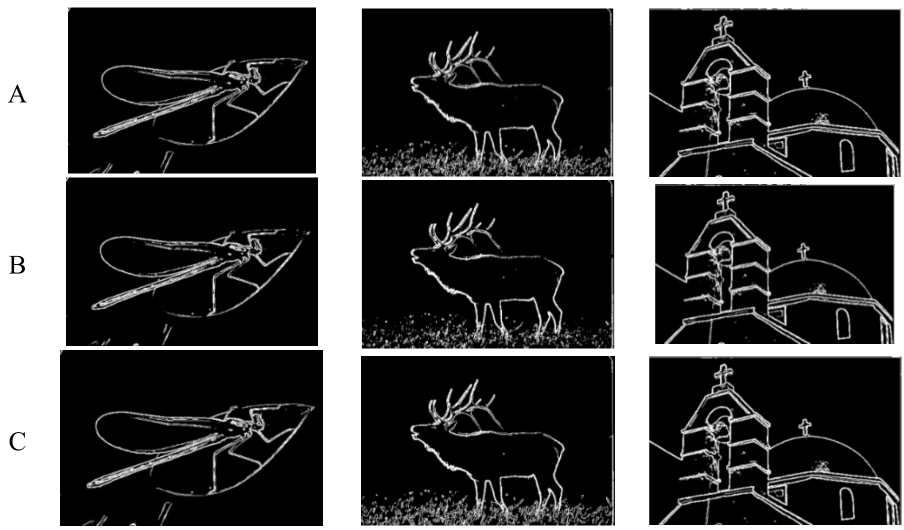

Fig. 4. A) u_{12} − Combination of Sobel and Canny filters, B) u_{13} − Combination of Sobel and Robinson filters, C) u_{23} − Result of application of combination of Canny and Robinson filters.

The union filters u_{12}, u_{13}, u_{23} were evaluated according to the formula (7) and

$$|u_{12}| = 15\ ,\ |u_{13}| = 5\ ,\ |u_{23}| = 80$$

Among these fusion filters, u_{23} - Canny and Robinson filter combination (7) was found to be the most optimal by evaluation:

$$u^{pair}_{opt} \sim u_{23}$$

The 3 filter combinations selected above were tested for the T_o image (Figure 5).

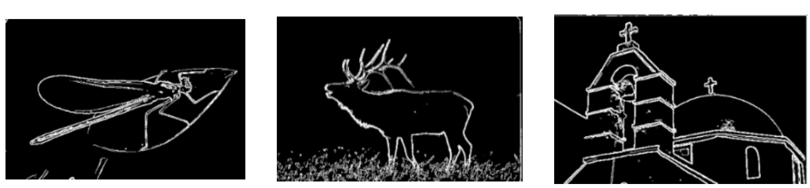

Fig. 5. u_{123} − result of applying a combination of Sobel, Canny and Robinson filters.

u_{123} was evaluated by the combination of filters (7) and compared with filters u^1_{opt} , u^{pair}_{opt} :

$$\left|u^1_{opt}\right| = 0\ ,\ \left|u^{pair}_{opt}\right| = 0\ ,\ |u_{123}| = 100$$

The filter with the most votes, u_{123} was recognized as the most effective filter:

$$u_{opt} \sim u_{123}$$

During the calculation experiment, all filters and their combinations in different combinations were evaluated according to the indicator (7) and their average values are presented in the table below.

Table 2. Contour detection filters (7) average values by indicator.

Filter	Filter designation	B indicator values (%)
Sobel	u_1	45.93
Canny	u_2	27.57
Robinson	u_3	46.22
Sobel+Canny	u_{12}	48.72
Sobel+Robinson	u_{13}	47.05
Canny+Robinson	u_{23}	49.21
Sobel+Canny+Robinson	u_{123}	49.72

As a result of computational experiments, the combination of u_{123} filters was determined to be the optimal filter for detecting the contour of the object, because the contour covered the most points (49.72%) with the image extracted by the expert.

Below are the test results obtained on a set of plant leaf images. The number of images of plant leaves is 61 [30,31]. However, the extracted plant leaf image set does not have contour expertly extracted images. Therefore, visual inspection is used in the assessment.

A set of plant leaf images was pre-processed using the proposed approaches presented in the image processing section above (Figure 6).

A

B

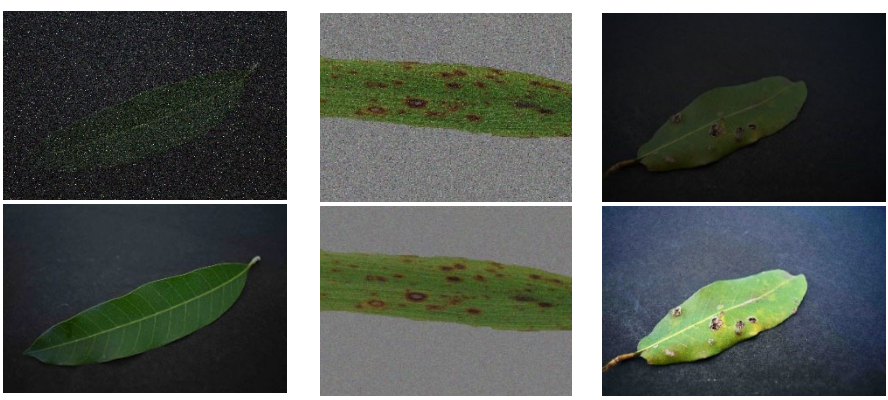

Fig. 6. A) Original image, B) pre-processed image.

From Figure 6 B, it can be seen that image quality is greatly improved with image preprocessing.

In order to evaluate the effectiveness of the pre-processing approach in separating the contour of the object, the fusion filters u_1 , u_2 , u_3 and u_{12} , u_{13} , u_{23} , u_{123} were applied to the image obtained as a result of its processing (Figure 7).

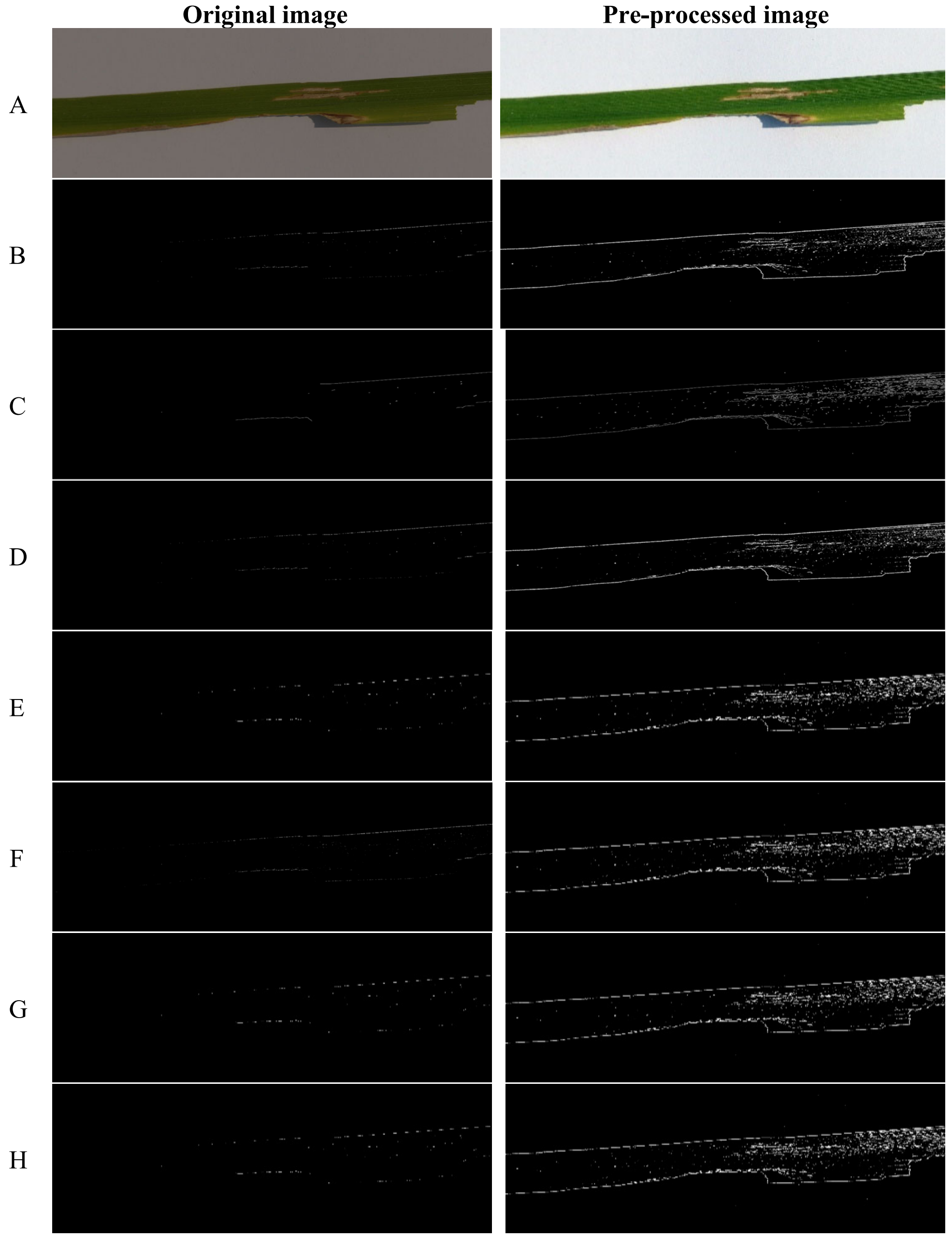

Figure 7. A) Original image, B) $u_1 -$ Sobel filter, C) $u_2 -$ Canny filter, D) $u_3 -$ Robinson filter, E) $u_{12} -$ Sobel and Canny filters, F) $u_{13} -$ Sobel and Robinson filters, G) $u_{23} -$ Canny and Robinson filters, H) $u_{123} -$ result of applying a combination of Sobel, Canny and Robinson filters.

In Figure 7, it can be seen that the contours of the object are more fully separated with the pre-processing of the image. The use of a combination of Sobel, Canny and Robinson filters allows to obtain a detailed outline of the object in its entirety.

6 Image datasets

The following table provides information about the set of images used in the computational experiment.

Table 3. Information about the image dataset.

Dataset name	Sample image	Number of image	Image format
BSDS500 [29]		100	.jpg
Rice Leaf Diseases Dataset [31]		25	.jpg
Plant Leaves for Image Classification [30]		36	.jpg

7 Conclusion

In this research work, the issue of object contour detection during image processing was studied. According to literature analysis, Canny, Sobel and Robinson filters, which are considered to be popular and classical methods of contour separation, were selected for computational experiments. Initially, the BSDS500 image set, which contains expertly delineated images, was used. Various combinations of selected filters were tested for these images. The image contour resulting from the combination of the applied filters was evaluated by an expert according to the pixel compatibility with the extracted image. The following conclusions were formed from the results of the calculation experiment:

– The use of their combinations in different combinations compared to separately obtained contour separation filters allows to increase the number of contour points in the image;
– The combination of Sobel, Canny and Robinsin filters (7) was found to be effective in determining the contour of the object by evaluation;
– Using the proposed image preprocessing approach in processing a set of plant images can improve image quality and provide a more complete separation of plant leaf contours in this processed image.
– The above-mentioned methods of object contour detection in the image are important in automating the analysis of plant leaf image sets. These techniques allow field professionals to collect valuable information in classifying plant species and monitoring plant health.

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