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Optimisation of Image Morphology Operations with Enhancement and Convolution in Tomato Leaf Disease Symptom Recognition

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A B S T R A C T

Tomato (*Solanum lycopersicum*) is an important horticultural crop that is highly susceptible to various leaf diseases such as leaf spot, bacterial wilt, and fruit rot, which significantly reduce yield and quality. This study applies digital image processing techniques including pre-processing, morphology, enhancement, and convolution to improve the recognition of disease symptoms on tomato leaves. Pre-processing using grayscale conversion and median blur effectively reduces noise and sharpens essential details, while morphological operations (erosion and dilation) highlight structural features of infected areas. Enhancement techniques increase image contrast, making the distinction between healthy and diseased tissue more visible. Convolution methods with kernels such as Sobel and Gabor further emphasize edges and texture patterns of leaf lesions. Experimental results show that these methods improve pixel intensity distribution and enhance the visibility of disease symptoms, thereby increasing diagnostic accuracy. The integration of these techniques demonstrates the potential for early detection and classification of tomato leaf diseases, enabling more effective disease management and prevention of crop losses.

1. Introduction

Tomato (Solanum lycopersicum) is one of the horticultural crops that has high economic value and is an important commodity in various countries, including Indonesia [1]. Optimal tomato production is strongly influenced by plant health conditions. Diseases are very easy to attack these tomato plants such as bacterial wilt, leaf spot, and fruit rot, which can cause a significant decrease in yield [2]. Therefore, early detection and classification of disease symptoms in tomato plants is essential for effective control and prevention of further spread.

Tomato diseases can be detected in various ways, such as how the disease attacks the leaves [3]. However, the diverse shapes of tomato leaves are not easy for humans to detect, especially for ordinary farming communities. So that technology can help detect tomato disease through leaf texture. In a study on grape leaf disease recognition, convolution with Sobel kernel was used to detect the edges of infected leaves. This edge detection helped to separate healthy from diseased leaf parts, which were then further analyzed to identify specific symptoms.

A process that aims to change the shape of an object in the original image is an image morphology technique. Grayscale images and binary images are carried out in the process [4].Image morphology techniques offer a powerful approach to detecting and classifying disease symptoms in tomato plants. Image morphology involves the use of image processing algorithms to extract visual features from infected tomato leaves and fruits. These features include aspects of colour, texture, and shape that can be used to automatically identify the type of disease. The first step is to convert the tomato leaf image from color to grayscale to reduce data complexity and focus on light intensity, which is important for morphological and convolution operations. Erosion will be applied to remove small noise and irrelevant details from the leaf image, such as small spots or shadows. After that, dilation is used to enlarge and restore the original shape of the infected area, so that the disease symptoms can be seen more clearly.

Digital image processing technology offers a potential solution for disease symptom recognition in tomato plants [5]. By using image morphology techniques, important features of disease symptoms can be extracted and analysed automatically. Morphological techniques involve mathematical operations on images to identify the structure and shape of objects in the image. In this context, image enhancement and convolution play a key role.

With the aim of improving and enhancing image quality for the better is the process of image enhancement [5]. Image enhancement aims to improve image quality so that relevant features can be seen more clearly. These techniques include contrast adjustment, edge sharpening, and noise removal. On the other hand, convolution is a mathematical process used to extract features by applying a specific kernel to the image. Convolution can help in identifying specific patterns associated with disease symptoms.

Image is another term for picture, as one of the multimedia components that has a very important role as a form of visual information [6]. Images have characteristics that other types of data do not have because they are rich with information. A digital image can be a type of vector or bitmap depending on whether the resolution of the image is fixed or changing. Bitmap images have a limited number of pixels and the number of pixels in the rows and columns of a bitmap image cannot change. A pixel is the smallest individual element in an image and stores the colour description value at that point. If a bitmap image is enlarged, the image looks broken. Generally, pixels are stored on computers as bitmap images or raster maps, in the form of small 2D integer arrays and are transmitted or stored in a compressed form. And the origin of vector images is from mathematical geometry, where a vector consists of points that have direction and length. Generally, bitmap and vector elements are combined in an image. For example, a billboard has text (vector) and a photo (bitmap). Digital images can be viewed with image viewing software such as Windows photo viewer. Web browsers can view standard image formats, such as GIF, JPEG, and PNG, while web browsers view the SVG format [7].

This research aims to optimise the use of image morphology techniques through enhancement and convolution in the process of recognising disease symptoms in tomatoes using digital image processing. By combining these two methods, it is hoped that an increase in accuracy and efficiency in disease detection can be achieved, which in turn will help farmers take early preventive action.

2. Research Method

This research uses an experimental approach with the main stages including image data collection, image preprocessing, application of image morphology techniques, and convolution in the recognition of disease symptoms in tomato leaves. The following is a detailed explanation of each stage:

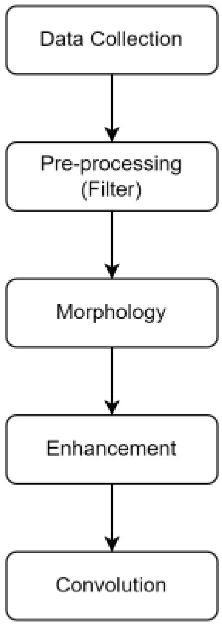


Figure 1. Flow of Researh Method

2.1. Image Data Collection

The image data used in this study comes from the image data repository available on the Kaggle platform, an online site that provides various resources and competitions in the field of data science and coding for image analysis and processing for various technological applications and scientific research. The process of collecting this dataset was done by downloading it through the link: https://www.kaggle.com/datasets/kaustubhb999/tomatoleaf .

The dataset has different disease types for tomato leaves including: Tomato_mosaic_virus, Target_Spot, Bacterial_spot, Tomato_Yellow_Leaf_Curl_Virus, Late_blight, Leaf_Mold, Early_blight, Spider_mites, Two-spotted_spider_mite, Tomato_healthy and Septoria_leaf_spot.

The different disease symptoms on tomato leaves were converted to greyscale to simplify the data by removing colour information that may not be relevant for detecting disease symptoms, and focusing on differences in light intensity, which is important for identifying infected areas. In addition, median blurring is relevant for cleaning the image of such noise without destroying edges or other important details that are indicative of disease symptoms. This helps to ensure that symptomatic features such as lesions or texture changes can be detected more accurately, as illustrated in Figure 2, which shows samples of tomato leaf images used in this study.

Figure 2. Tomato Leaves

2.2. Image Preprocessing

The initial stage in image processing before processing is Preprocessing [8]. Image processing is a field of computer science that aims to improve the quality of images, make them easier to interpret by humans and computers, or improve their quality [9]. In the preprocessing stage, the images that have been collected will be processed to improve their quality. The preprocessing process includes:

1. Contrast Adjustment: Increases the difference between light and dark areas in the image so that important features are more visible.
2. Edge Sharpening: Uses a sharpening filter to sharpen the edges of objects in the image.
3. Penghapusan Noise: Using filtering techniques such as median or Gaussian filters to reduce unwanted noise in the image.

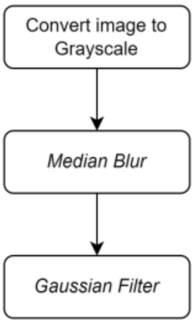


Figure 3. Flow of Image Preprocessing Process

Based on Figure 3, the image will have its colour channel changed from RGB to Grayscale. Converting images from color to grayscale reduces the complexity of the data by removing color information that is not relevant for symptom analysis. It also focuses on light intensity, which is more significant in detecting visual features such as edges and textures. This conversion reduces the dimensionality of the data, speeds up the processing process, and helps other techniques, such as edge detection, work more effectively. This is necessary to reduce the information that will be stored in a pixel. The grayscale conversion is performed using Formula (1) as follows:

$$Grayscale = 0.299R + 0.587G + 0.114B \quad (1)$$

In Formula (1), R is the red channel value, G is the green channel value, and B is the blue channel value. The higher weight on the green channel reflects the human eye's sensitivity to green light, ensuring that the grayscale image maintains essential luminance information for analysis. After this step, the image undergoes median blur to remove noise while preserving edge details, followed by a Gaussian filter to smooth the image and enhance the overall quality.

Furthermore, the grayscale image will be subjected to a Median Blurring process whose function is to reduce noise in the image [10]. The adaptive median filter method performs spatial processing to determine which pixels in the image are affected by noise impulses [11]. The adaptive median filter classifies pixels as noise by comparing each pixel in the image with its neighbouring pixels [12]. The image that has been median blurred will enter the Gaussian Filter stage.

For images subject to bipolar and unipolar impulse noise, the median filter is very effective [13]. It reduces noise very well for several types of noise, with lower blur levels than linear smoothing filters for the same image size [14]. The image that has been median blurred will enter the Gaussian Filter stage.

Gaussian filter is one of the linear filters with weighting values for each member chosen based on the shape of the Gaussian function because it has a kernel centre [15]. Due to light reflection and the sensitivity of the light sensor on the camera itself, the Gaussian filter is one of the excellent techniques for removing normal spread noise, which is often seen in images resulting from the digitisation process using a camera [16]. The Gaussian filter calculation is expressed in Formula (2) as follows:

$$\frac{h(x,y)}{c} = e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

In this formula, h(x,y) represents the Gauss kernel matrix element at position (x,y), ccc is a constant used for normalisation, and σ (sigma) denotes the standard deviation value, which controls the spread of the Gaussian function. A larger σ produces more blurring, while a smaller σ maintains finer details.

The preprocessing process ends with the masking method, where the mask that has been formed from the edge detection process will be used to remove the background in the original image. This process will combine the image with all black pixels, the original image, and then the mask. The output image that will be used can be seen in Figure 4.

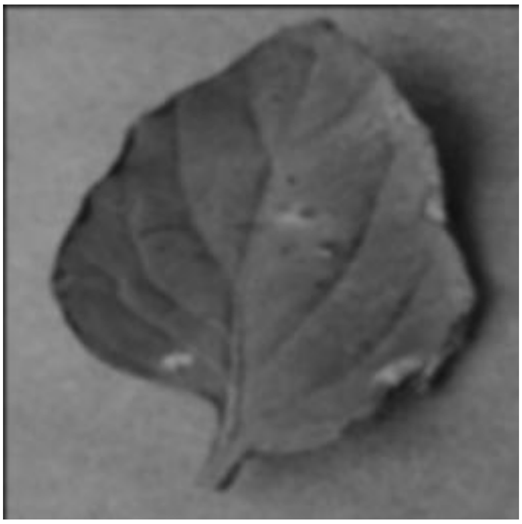


Figure 4. Image Preprocessing Output Results

2.3. Image Morphology

Changing the shape of objects from the original image is the process of image morphology operations. This process is carried out on binary images and grayscale images [17]. Grayscale image is a data matrix whose values represent the intensity of each pixel ranging from 0 to 255. Each pixel requires 8 bits of memory [18].

The equation for conversion to grayscale image is shown in Formula (3).

$$Average = R+G+B/3 \quad (3)$$

Black and white consisting of two grey degree values is a binary image [19]. Binary images are represented with only two colour intensities at each pixel, namely 0 and 1, where the value 1 represents black and the value 0 represents white. In a binary image, the object pixels are 1 and the background pixels are 0.

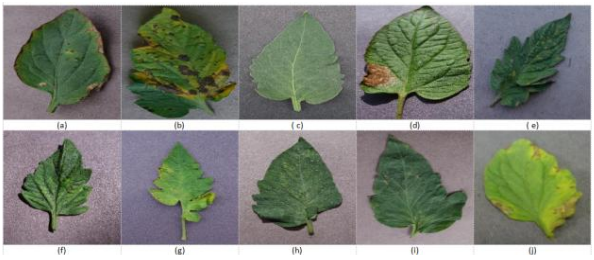


Figure 5. Sample Images From Each Dataset: (a) Bacterial Spot, (b) Leaf Blight, (c) Healthy, (d) Leaf Blight, (e) Leaf Mould, (f) Mosaic Virus, (g) Septoria Leaf Spot, (h) Spider Mite, (i) Target Spot, (j) Yellow Leaf

Morphology in this study there are several operations used, including:

a. The dilation operation aims to increase the size of the segment in the layer around the object.

b. The erosion operation is a process that results in a smaller image size (the opposite of the dilation operation).

The term morphology is often used in digital image processing to process the shape or structure of objects in such a way as to obtain their shape and characteristics. In this processing, mathematical morphology is a tool used to extract components in the image that will be used to present and describe the shape in the image [20].

2.4. Enhancement

With the aim of improving and enhancing the image quality for the better is the process of image enhancement [21]. Depending on the goal to be achieved, this process is usually experimental and subjective.

Enhancement is an initial process in image processing (preprocessing) to improve the quality of images containing noise, images that are too bright or dark, less sharp and even blurred or blurry [22]. Image quality needs to be improved because the images used for discussion are of poor quality, noisy, too bright or dark, or appear unclear or blurry [23].

In many image processing applications, this technique is essential for identifying diseases in tomato leaves as it helps to increase the visibility and contrast of the main characteristics that indicate disease.

2.5. Convolution

Image convolution is a technique of smoothing or sharpening an image by replacing the pixel values with a number of pixel values that match or are close to the original pixels but the size of the image remains the same, unchanged [24].

Convolution, which is widely used in image processing for feature extraction, has two functions f(x) and g(x), as defined in Formula (4).

$$h(x) = f(x) * g(x) = \int_{-\infty}^{\infty} f(a)g(x-a)\,da \quad (4)$$

Description:

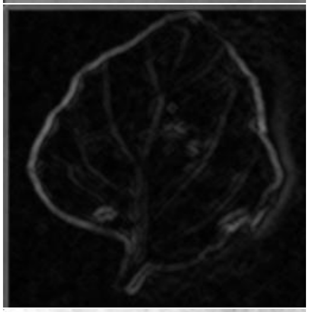
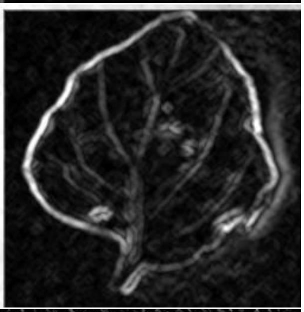
- The * sign denotes the convolution operator, and the variable a is a dummy variable.
- g(x) is called the convolution kernel or mask.
- The kernel g(x) can be thought of as a window that is shift-operated on the input signal f(x).
- The sum of the multiplication of the two functions at each point is the convolution result expressed by the output signal h(x).

To perform convolution, the convolution kernel of each pixel is moved and the result is stored in a new matrix [25]. In some image processing processes, conversion is also useful. These include edge detection, edge sharpening, image quality improvement, noise removal, image smoothing and softening, and highlight reduction.

3. Result and Discussion

The stages of image processing carried out in this study include Pre-processing, Morphology, Enhancement, and Convolution. The overall results of these stages are presented in Table 1.

Table 1. Image Processing Results

Image Processing Stages	Results
Before Preprocessing	
After Preprocessing	
Morfology	
Enhancement	
Convolution	

As shown in Table 1, image processing is carried out by testing with the Pre-processing, Morphology, Enhancement, and Convolution methods in the recognition of disease symptoms on tomato leaves. Enhancement, in particular, plays an important role in clarifying significant features, thereby facilitating the identification and analysis of disease symptoms. This test only performs a strict evaluation of the visual appearance, with enhancement conducted using image processing software such as MATLAB or Python with the OpenCV library.

3.1. Pre-processing

Pre-processing is an important stage in image processing, especially for identifying diseases on these tomato leaves. In this step, the image is converted to grayscale. This reduces the complexity of the image because grayscale images have one channel compared to RGB images which have three channels. Also, image processing more effectively focuses on light intensity differences rather than colour differences.

Median blur is also used to remove noise from an image while preserving the edges. Median blur is excellent for removing "salt and pepper" type noise while smoothing the image and reducing noise. After reprocessing, median blur is used for smoothing the image and reducing noise.

Common pre-processing steps in image processing include converting the image to grayscale and using median and Gaussian filters. These processes help to reduce noise and sharpen important details in the image, thus preparing the image for further processing such as segmentation or feature detection. The results of this stage can be observed in Figure 6.

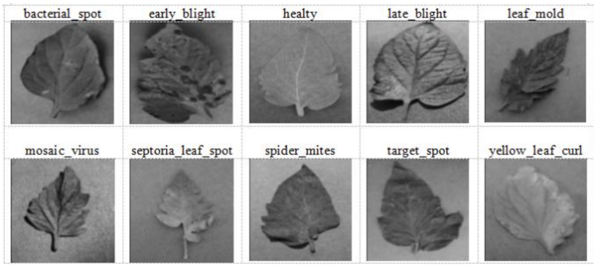


Figure 6. Image preprocessing output results

Table 2. Comparison Image Before and After Pre-Processing Image AG-S-001.jpg

Row	Coll	OriginalValue	Processed Value	Absolute Difference
10	20	147	138	**9**
50	60	122	129	**7**
100	120	83	79	**4**

Table 2 shows the significant difference in the quantitative pixel value scores between the original image and the pre-processed version. The Absolute Difference after filtering shows a form of smoothing that is more noticeable in areas of high variation.

3.2. Morphology

Image morphology techniques are used for shape analysis, filtering, noise reduction, and extraction of geometric and structural features from binary or grey-scale images. The erosion function is used to shrink objects in binary images. The principle of erosion is to shrink an object by "eroding" its edges. Also, the dilation function is used to enlarge objects in a binary image and add pixels around the edges of the object.

Using basic operations such as erosion and dilation, as well as a combination of dilation and then erosion called occlusion, objects in the image are enlarged slightly through dilation, which adds pixels at the edges of the objects. In addition, this sealing process fills in small holes and connects objects that are almost separated. The results of this stage can be observed in Figure 7.

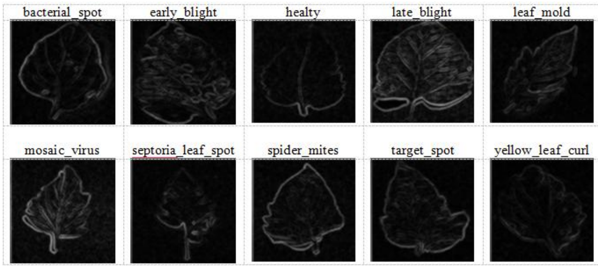


Figure 7. Image Morfology Output Results

Table 3. Absolute Difference Morphology Image AG-S-001.jpg

Row	Coll	Preprocessing Value	Morfology Value	Absolute Difference
10	20	138	4	**134**
50	60	129	9	**120**
100	120	79	9	**70**

Table 3 compares the absolute difference value before and after the morpholoy process. As indicated in the table, the absolute difference in image AG-S-001.jpg demonstrates that the morphological procedures (dilation and erosion) have a considerable impact on the image, drastically diminishing pixel intensity in certain locations. The effect of morphological processing is most visible in high contrast photos, particularly in areas near objects or image edges.

3.3. Enhancement

Image enhancement is used for image processing to improve the quality of an image to make it easier to analyse or interpret. Contrast enhancement is particularly important when analysing tomato leaf blight images, as it helps to distinguish healthy and infected areas more clearly. Enhancement techniques change the intensity values of pixels in an image so that low intensity values are reduced and high intensity values are increased, which in turn increases the overall contrast of the image. By increasing the contrast, infected areas are easier to identify and analyse, thus helping to diagnose the disease more accurately. The results of this stage can be observed in Figure 8.

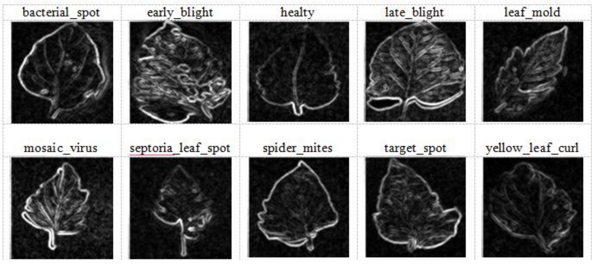


Figure 8. Image Enhancement Output Results

Table 4. Absolute Difference Before and After Enhancement Image AG-S-001.jpg

Row	Coll	Morfology Value	Enhancement Value	Absolute Difference
10	20	4	7	**3**
50	60	9	25	**16**
100	120	9	25	**16**

Table 4 shows that following enhancement, the intensity of pixels in some sections of the image is dramatically reduced, with an absolute value difference ranging from 3 to 8. This significant drop demonstrates that enhancement, which may include operations like thresholding or contrast reduction, is effective in lowering intensity values in brighter pixels.

3.4. Convolution

Image processing uses convolution to identify features in an image; this process is particularly relevant for finding diseases in tomato leaves through image analysis. In image processing, convolution is used between an image and a filter (or kernel) to extract certain features from the image. The kernel used is 3 by 3 and moves across the image, and serves to detect various features such as tep Using image convolution, we can effectively and efficiently identify diseases in tomato leaves. This is very helpful in general crop management and proper farming. The results of this stage can be observed in Figure 9.

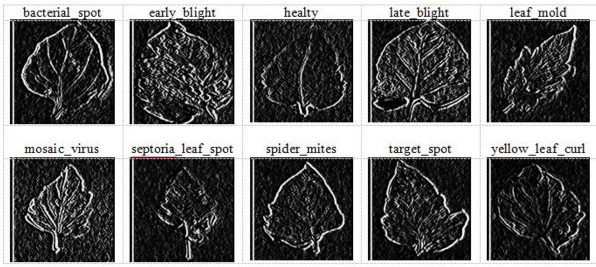


Figure 9. Image Convolution Output Results

Table 5. Absolute Difference Before and After Convolution Image AG-S-001.jpg

Row	Coll	Enhancement Value	Convolution Value	Absolute Difference
10	20	7	0	**7**
50	60	25	0	**25**
100	120	25	-32	**57**

Table 5 shows that the absolute difference between the enhancement and convolution result values indicates that enhancement provides a more consistent change and increase in pixel value, whereas convolution can cause more drastic changes, such as a decrease in pixel value at specific locations.

Effectiveness of Preprocessing and Morphological Operations Enhances contrast and helps in edge detection and segmentation. Histogram equalization is a very useful technique for enhancing contrast in images. In the context of disease symptom recognition in tomato leaves, this technique helps to clarify the difference between healthy and infected regions. By spreading the pixel intensities evenly, previously hidden or obscure features become more visible, facilitating the detection process and subsequent analysis. The convolution layer applies a convolution operation on the input image, resulting in a feature map. Each filter in the convolution layer captures specific features, such as vertical edges, horizontal edges, or certain texture patterns. The combination of these feature maps helps in recognising disease symptoms.

4. Conclusion

This research shows that image processing techniques in identifying diseases on tomato leaves can be more effective and efficient in recognising diseases on tomato leaves. The Pre-Processing method with an absolute difference value of (9,7,4), Morphology with an absolute difference value of (130,120,70), Enhancement with an absolute difference value of (3,16,16), and Convolution with an absolute difference value of (7,25,57) successfully increases the accuracy in detecting tomato leaves affected by disease. Therefore, with this technology, early detection and classification of disease symptoms in tomato plants becomes very important for effective control and prevention of further spread. So that in its implementation, this technology can help farmers manage their crops better and more productively. In addition, this technology can also help farmers anticipate and prevent economic losses caused by plant diseases.

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