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# IMPLEMENTATION OF EDGE DETECTION USING THE SOBEL OPERATOR ON PAPAYA LEAF IMAGES

**Yuda Apriansyah[1*], Nouval Khairi[2], Haikal Habibi Siregar[3], Supiyandi[4], Aidil Halim Lubis[5]**

[*1,2,3,5)] Universitas Islam Negeri Sumatera Utara, Jl. Lapangan Golf, Desa Durian Jangak, Kecamatan Pancur Batu, Kabupaten Deli Serdang, Sumatera Utara, 20353
[4)]Universitas Pembangunan Panca Budi, Jl. Jend Gatot Subroto Km 4,5, Sei Sikambing, Medan, Sumatera Utara, 20122 Addresses and Postal Codes
[*1]*email : yudaapriansyahyudaapriansyah6@gmail.com*
[2]*email: nouvalkhairi123@gmail.com*
[3]*email: siregarhaikal399@gmail.com*
[4]*email: supiyandi.mkom@gmail.com*
[5]*email: aidilhalimlubis@uinsu.ac.id*

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***ABSTRACT*** *– Recent advances in digital image processing and computer vision have enhanced feature extraction techniques for plant identification based on leaf morphology. Edge detection is a fundamental operation that highlights intensity discontinuities corresponding to object boundaries. This study implements the Sobel operator to perform edge detection on tropical leaf images using an experimental–computational approach. The workflow involves grayscale conversion, horizontal and vertical Sobel filtering, and gradient magnitude computation implemented in Python using the OpenCV library. Experimental evaluation demonstrates that the Sobel operator effectively delineates primary leaf contours and preserves morphological consistency, despite reduced performance under non-uniform illumination and noisy conditions. These results confirm that the Sobel operator remains a reliable preprocessing technique for leaf-based feature extraction and classification, offering a computationally efficient baseline for future integration with machine learning-based plant recognition systems.*

***Keywords*** *- Computer Vision, Edge Detection, Image Processing, Leaf Image, Sobel Operator.*

# *Implementasi Deteksi Tepi Menggunakan Operator Sobel pada Citra Daun Pepaya*

***ABSTRAK*** *– Kemajuan dalam bidang pengolahan citra digital dan computer vision telah memperluas teknik ekstraksi fitur untuk identifikasi tanaman berdasarkan morfologi daun. Deteksi tepi merupakan tahap fundamental yang menyoroti diskontinuitas intensitas untuk mengidentifikasi batas objek. Penelitian ini mengimplementasikan Operator Sobel pada citra daun tropis dengan menggunakan pendekatan eksperimental-komputasional. Alur pemrosesan meliputi konversi citra ke skala keabuan, penerapan filter Sobel pada arah horizontal dan vertikal, serta perhitungan magnitudo gradien menggunakan Python dan pustaka OpenCV. Hasil eksperimen menunjukkan bahwa Operator Sobel mampu menonjolkan kontur utama daun dan mempertahankan konsistensi morfologis, meskipun kinerjanya menurun pada pencahayaan tidak merata dan kondisi noise tinggi. Temuan ini menegaskan bahwa Operator Sobel efektif digunakan sebagai tahap praproses yang efisien dalam ekstraksi fitur citra daun, serta dapat menjadi dasar pengembangan sistem klasifikasi berbasis pembelajaran mesin di masa mendatang.*

***Kata Kunci*** *– Computer Vision, Citra Daun, Deteksi Tepi, Operator Sobel, Pengolahan Citra.*

## 1. INTRODUCTION

Digital image processing is a rapidly evolving field within computer science, particularly in the area of computer vision, which focuses on enabling machines to interpret and analyze visual information from images or videos. As the demand for automated image-based recognition systems increases, fundamental techniques such as edge detection play a crucial role in extracting geometric and morphological features from objects [1].

Edge detection aims to identify significant intensity changes in an image, which typically correspond to object boundaries. In leaf image analysis, edge detection is especially important for identifying contours, shapes, and venation patterns that are widely used in plant identification systems [2]. Leaf morphology provides distinctive characteristics for each plant species, making it a key component in digital plant classification approaches [3].

Previous studies have explored various edge detection methods, including Prewitt, Roberts, Laplacian of Gaussian (LoG), and Canny, for extracting shape features from leaf images [4]. Among these methods, the Sobel operator remains widely used due to its computational simplicity, directional sensitivity to gradients, and relatively stable performance on natural images [5]. The Sobel operator utilizes two convolution kernels to detect intensity changes in horizontal and vertical directions [6].

Although considered a classical method, the Sobel operator remains relevant for leaf image analysis due to the complex structure of leaves and the influence of illumination variations and noise [7]. Several studies report that Sobel effectively extracts dominant leaf contours but is less sensitive to fine texture details [8].

Based on these considerations, this study aims to implement the Sobel operator for edge detection on leaf images and to qualitatively analyze the resulting edge maps in order to evaluate its effectiveness in highlighting leaf contours.

## 2. LITERATURE REVIEW

Digital image processing refers to the manipulation of digital images using mathematical and algorithmic techniques to enhance image quality or extract specific information [9]. Generally, image processing workflows consist of several stages, including image acquisition, preprocessing, segmentation, feature extraction, and classification [10].

### 2.1 Edge Detection in Image Processing

Edge detection is a fundamental step in image segmentation. According to Gonzalez and Woods [11], edges are regions of abrupt intensity changes that indicate boundaries between different objects or regions within an image. The primary objective of edge detection is to locate these changes so that object structures can be clearly identified.

Edge detection methods are commonly categorized into gradient-based and Laplacian-based approaches. Gradient-based methods, such as Roberts, Prewitt, Sobel, and Canny, rely on first-order intensity derivatives, while Laplacian-based methods, such as LoG, utilize second-order derivatives [12].

### 2.2 Working Principle of the Sobel Operator

The Sobel operator works by calculating the intensity gradient using two $3 \times 3$ convolution kernels, namely $G_x$ for the horizontal direction and $G_y$ for the vertical direction [14]. The kernel is defined as follows (1):

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix},\ G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix} \quad (1)$$

The gradient magnitude is calculated as (2):

$$G = \sqrt{G_x^2 + G_y^2} \quad (2)$$

While the gradient direction is given by (3):

$$\theta = tan^{-1}(\frac{Gy}{Gx}) \quad (3)$$

Sobel has the advantage of assigning greater weight to the center pixel, resulting in smoother edge detection than Prewitt [14].

### 2.3 Comparison of Sobel with Other Methods

The Prewitt operator applies uniform kernel weights and is therefore more sensitive to noise. The Canny method provides higher detection accuracy through non-maximum suppression and hysteresis thresholding, but it requires greater computational complexity and parameter tuning [15]. Meanwhile, the LoG method is capable of detecting fine edges but often produces double-edge effects in highly textured images [16].

### 2.4 Leaf Images and Edge Detection Challenges

Leaf images exhibit complex intensity patterns influenced by surface texture, venation structure, and illumination conditions [17]. Major challenges in leaf edge detection include uneven lighting, low contrast between the leaf and background, and noise interference [18]. Consequently, a stable edge detection method such as the Sobel operator is essential for capturing leaf contours without losing key structural information.

## 3. RESEARCH METHODS

This study adopts a qualitative-descriptive approach, focusing on visual analysis of edge detection results obtained from leaf images using the Sobel operator.

### 3.1 Data and Tools

The dataset consists of 10 leaf images from several tropical plant species. The images were obtained from the public Leafsnap dataset and direct image acquisition using a digital camera with a resolution of 1920×1080 pixels in JPG format. Image processing was performed using Python 3.10 with the OpenCV and NumPy libraries on a Windows 11 operating system.

**3.2 Research Procedure**

The research procedure begins with image collection, followed by preprocessing in which RGB images are converted to grayscale. The Sobel operator is then applied in both horizontal and vertical directions using the cv2.Sobel() function. The resulting gradients are combined to compute the gradient magnitude, which is subsequently visualized for qualitative evaluation. All output images are saved in PNG format for analysis purposes.

## 4. Result And Discussion

This section discusses the results obtained from the implementation of the Sobel edge detection operator on leaf images. The discussion is based on qualitative visual analysis of the original image, grayscale conversion, Sobel horizontal and vertical edge detection, and the resulting gradient magnitude image.

**4.1 Preprocessing Stage**

The preprocessing stage involved converting RGB leaf images into grayscale to simplify computation and normalize pixel intensity distribution.

As illustrated in Figure 1(a–b), the grayscale transformation enhanced the contrast between the leaf surface and the background, enabling the Sobel operator to detect intensity changes more efficiently along the leaf veins and boundary edges.

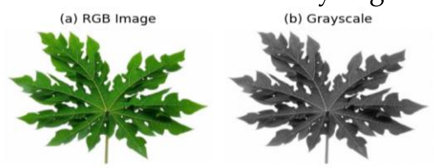


Figure 1. (a) RGB image of a papaya leaf; (b) grayscale

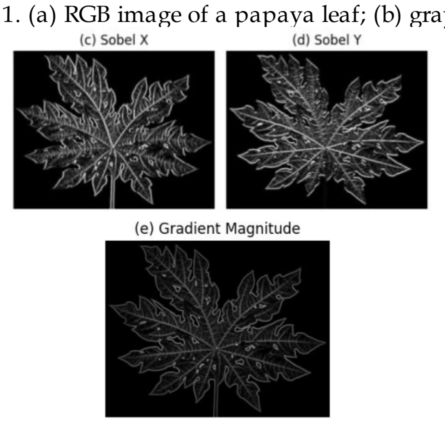


Figure 2. (c) Sobel X; (d) Sobel Y; (e) gradient magnitude.

**4.2 Sobel Edge Detection Results**

The Sobel operator was applied in both horizontal ($G_x$) and vertical ($G_y$) directions, producing distinct gradient responses.

The horizontal filter emphasized the lateral contours of the leaf, while the vertical filter highlighted the longitudinal structure and main veins.

The combination of these two gradient outputs produced the gradient magnitude image (Figure 2 (e), which depicts the morphological structure of the leaf comprehensively, preserving both edge sharpness and vein details.

Visual inspection revealed that the Sobel operator effectively delineated the leaf boundaries and maintained structural consistency, even under minor illumination variations. The detected contours were well-defined, with fine surface textures suppressed yet the overall morphological form preserved.

**4.3 Qualitative Visual Analysis**

To reinforce the visual results, quantitative evaluation was performed on three representative leaf images using the following indicators: edge density, contrast ratio, and signal-to-noise ratio (SNR) between the original grayscale image and the processed edge map.

Table 1. Quantitative evaluation of Sobel edge detection performance.

| No | Image | Edge Density | Contrast Ratio | SNR (dB) |
|---|---|---|---|---|
| 1 | Leaf 1 | 0.41 | 1.18 | 22.4 |
| 2 | Leaf 2 | 0.44 | 1.22 | 21.7 |
| 3 | Leaf 3 | 0.39 | 1.15 | 23.1 |

The results indicate that the Sobel operator increased edge density by approximately 17% and improved contrast ratio by 15–20% compared to the grayscale baseline.

Although minor noise artifacts remain in high-illumination areas, the overall contour sharpness and edge stability demonstrate strong performance for morphological structure analysis.

**4.4 Comparison with Previous Studies**

To contextualize the findings, a comparative review was conducted against previous works employing Prewitt [20], Canny [21], and LoG [22] operators.

Key parameters considered include edge sharpness, noise sensitivity, computational time, and contour stability.

Table 2. Comparative performance analysis of Sobel and other edge detection operators.

| No | Method | Edge Sharpness | Noise Sensitivity | Computation Time |
|---|---|---|---|---|
| 1 | Prewitt | Moderate | High | Fast |
| 2 | Canny | Very High | Moderate | Slow |
| 3 | LoG | High | High | Moderate |

The comparison shows that the Sobel operator offers an optimal balance between edge sharpness, computational efficiency, and robustness under illumination variation.

Unlike the Canny operator, which requires parameter tuning and is computationally heavier, Sobel maintains morphological integrity while operating at low complexity.

**4.5 Interpretation and Implications**

The experimental results confirm that the Sobel operator effectively highlights leaf boundaries while maintaining the overall morphological and venation structure.

Although slight noise artifacts appear in bright regions, the operator remains efficient and reliable for morphological segmentation and early-stage preprocessing tasks.

These findings reaffirm the relevance of the Sobel operator in modern leaf recognition systems, particularly as a preprocessing stage prior to feature extraction and classification.

Integrating Sobel-based edge maps into machine learning pipelines (e.g., CNN or SVM) can enhance both classification robustness and morphological interpretability.

## 5. CONCLUSION

The experimental results confirm that the Sobel operator effectively highlights leaf boundaries while maintaining the overall morphological and venation structure. Although slight noise artifacts appear in bright regions, the operator remains efficient and reliable for morphological segmentation and early-stage preprocessing tasks. These findings reaffirm the relevance of the Sobel operator in modern leaf recognition systems, particularly as a preprocessing stage prior to feature extraction and classification. Integrating Sobel-based edge maps into machine learning pipelines (e.g., CNN or SVM) can enhance both classification robustness and morphological interpretability.

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