Comparative Analysis of Edge Detection Techniques

Roberts · Sobel · Prewitt · Canny

What is Edge Detection?

Defining Discontinuities

Edge detection is a mathematical technique used to identify points in a digital image where the brightness changes sharply. These points are organized into a set of curved line segments termed "edges".

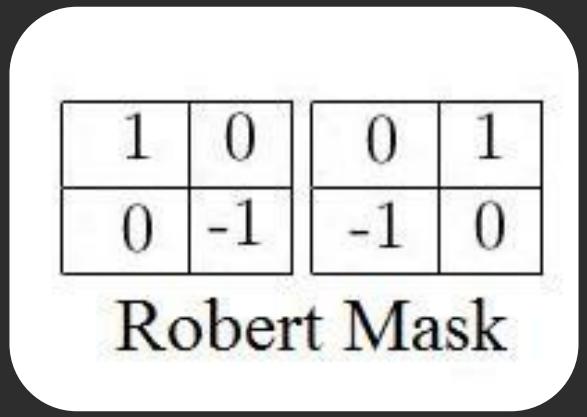
Why it Matters

· Reduces data volume while preserving structure.

· Critical for feature extraction and object recognition.

· Fundamental to computer vision pipelines.

Convolution Kernels (Masks)

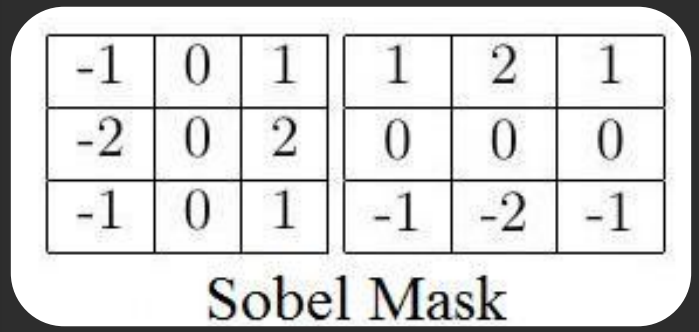


1	0	0	1
0	-1	-1	0

Robert Mask

Roberts

2x2 Diagonal Gradient. Uses minimal discrete differentiation.

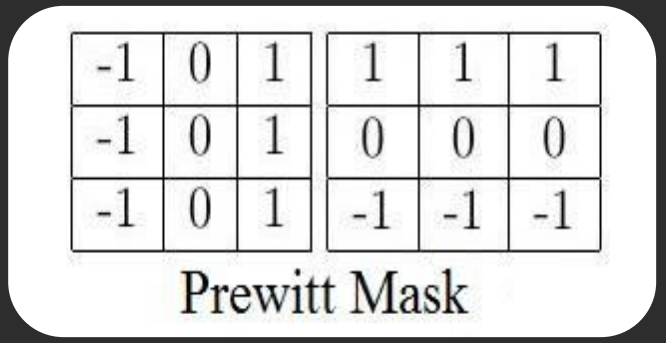


-1	0	1	1	2	1
-2	0	2	0	0	0
-1	0	1	-1	-2	-1

Sobel Mask

Sobel

3x3 Gaussian Smoothing + Differentiation. Reduces noise impact.



-1	0	1	1	1	1
-1	0	1	0	0	0
-1	0	1	-1	-1	-1

Prewitt Mask

Prewitt

3x3 Uniform Averaging. Similar to Sobel but lacks central weighting.

Mathematical Foundations

Gradient Calculation

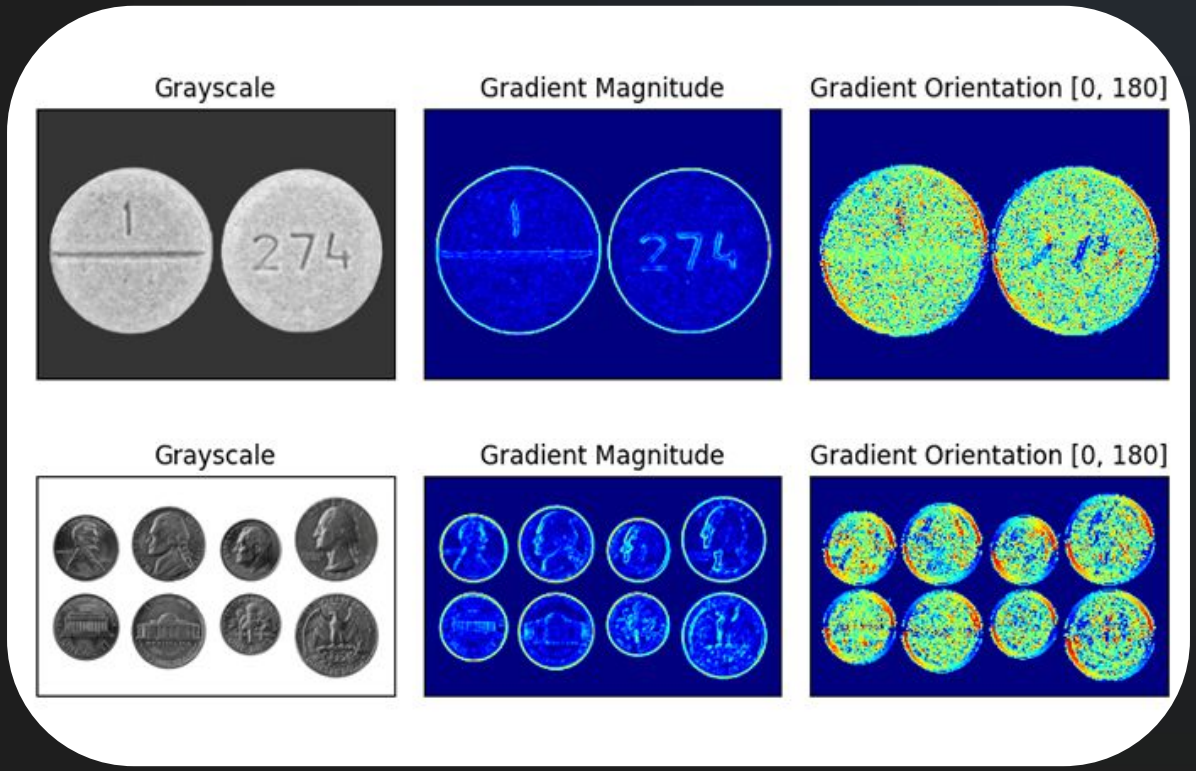
For operators like Sobel and Prewitt, the gradient magnitude **|G|** is calculated using the partial derivatives in the horizontal (Gx) and vertical (Gy) directions.

$$|G| = \sqrt{(Gx^2 + Gy^2)}$$

Orientation

The direction of the edge **Θ** is determined by the arctangent of the ratio of the derivatives.

$$\Theta = \arctan(Gy / Gx)$$



Roberts vs. Prewitt

Roberts Operator

Pros: Extremely simple and computationally cheap. Excellent for sharp, distinct edges with no noise.

Cons: Highly sensitive to noise due to the small 2x2 kernel. Offers no smoothing.

Prewitt Operator

Pros: Detects vertical and horizontal edges well. 3x3 kernel provides basic averaging.

Cons: The uniform averaging is often inferior to the Gaussian-weighted smoothing found in Sobel.

Sobel vs. Canny

Sobel Operator

Combines Gaussian smoothing and differentiation. It computes the gradient magnitude of image intensity at each point.

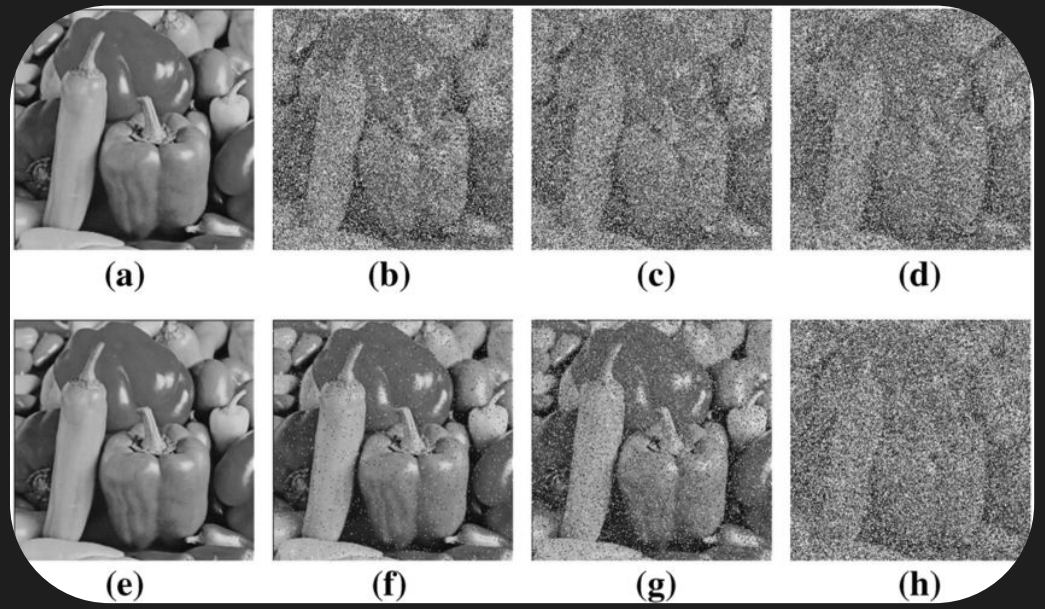
Result: Thicker, clearer edges than Roberts, with better noise resilience.

Canny Edge Detector

A multi-stage algorithm considered the "optimal" detector. It focuses on finding the true edges while suppressing false positives caused by noise.

Noise Robustness Analysis

Performance under Salt & Pepper, Gaussian, and Speckle Noise



Key Findings

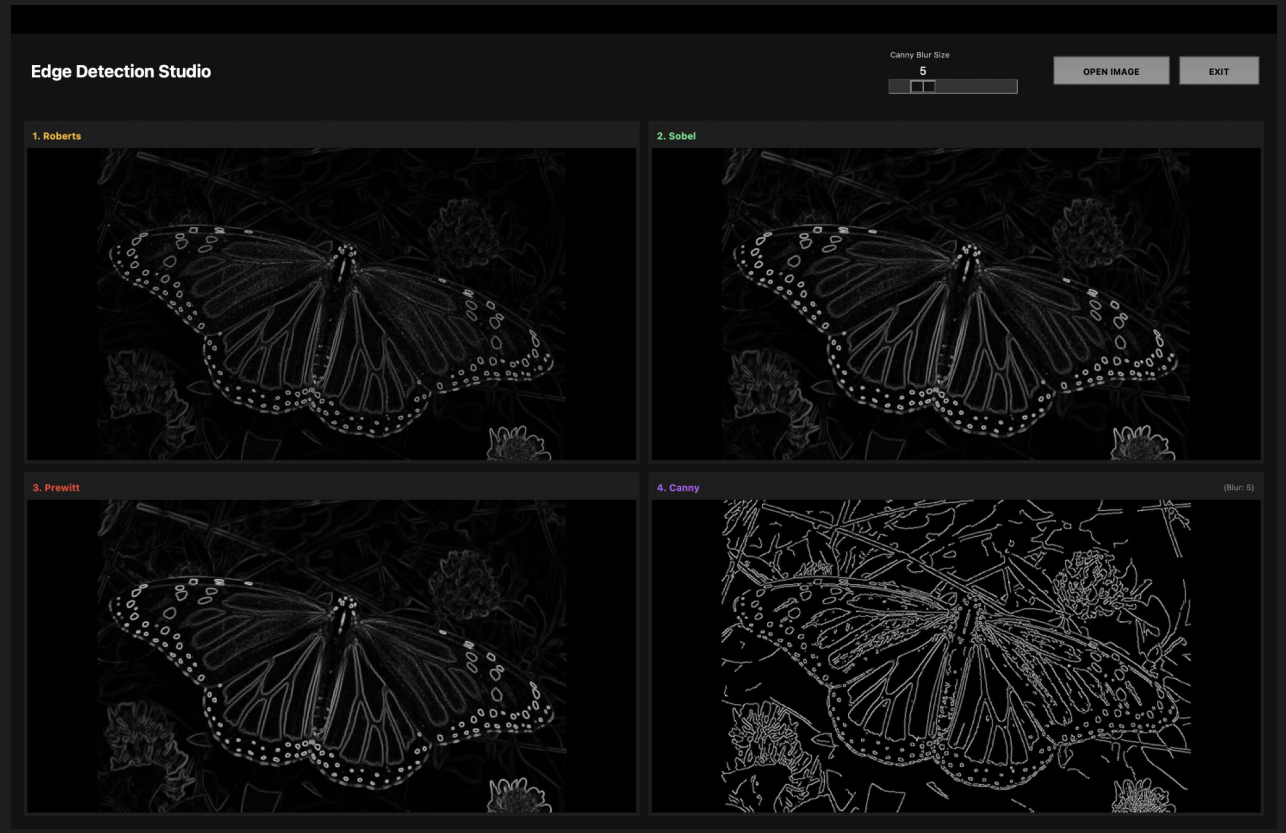
- ✓ **Canny:** Most robust. The initial Gaussian smoothing step effectively minimizes noise impact before edge extraction.
- ✓ **Sobel:** Moderate performance. Its averaging nature helps, but it still picks up some noise as edges.
- ✗ **Roberts:** Poor performance. They are highly sensitive to "Salt & Pepper" noise, detecting noise specs as false edges.

Implementation Demo

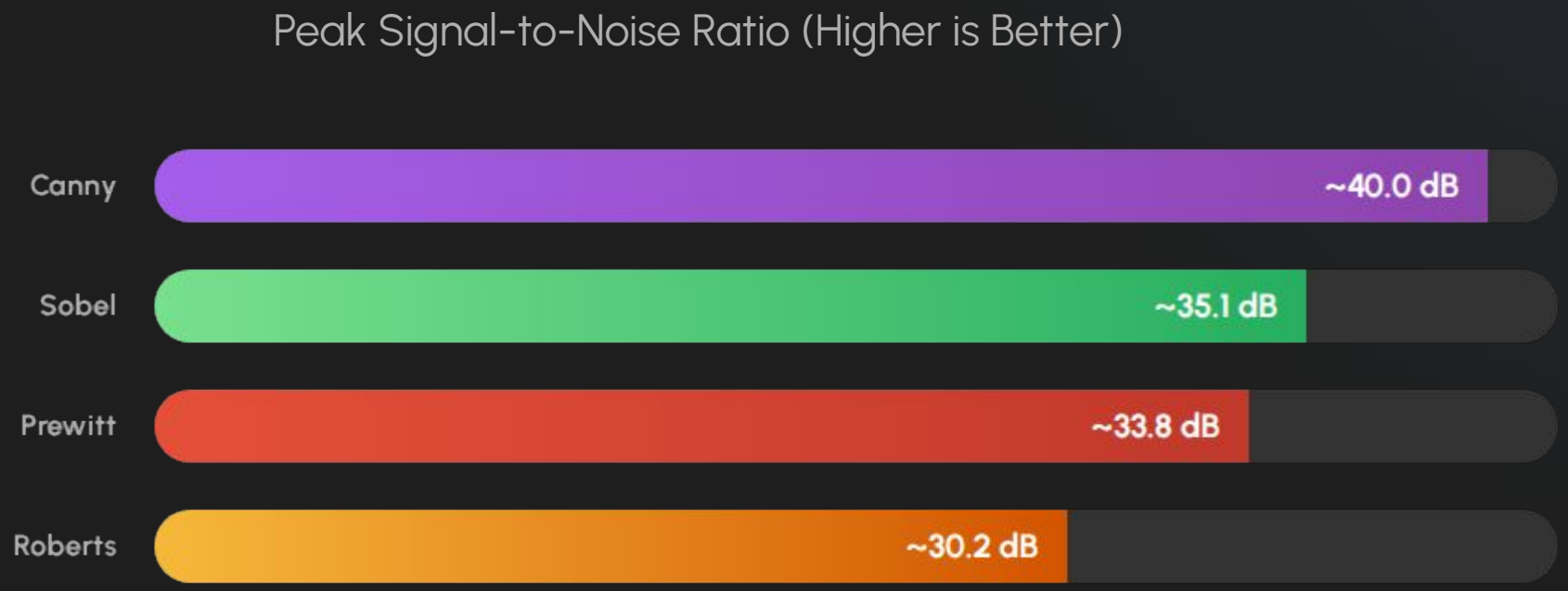
Interactive Studio

A Python application to compare these algorithms in real-time.

- ✓ **Live Comparison:** See Original, Roberts, Sobel, Prewitt, and Canny side-by-side.



Quantitative Analysis (PSNR)



Conclusion

- **Canny is Superior:** For general-purpose edge detection, Canny consistently outperforms others due to its hysteresis thresholding and noise reduction, though it is computationally more expensive.
- **Sobel is Efficient:** Sobel offers the best balance between performance and computational cost, making it ideal for real-time video processing.
- **Roberts is Limited:** While historically significant, Roberts is too sensitive to noise for most modern photographs but remains useful for synthetic, noise-free images.

Thank you!

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