Canny Edge Detection

A Key Technique in Image Segmentation

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Overview of Canny Edge Detection

- **Goals of the Canny Algorithm:**
  - **Low error rate**: Minimize false edges and missed edges.
  - **Well-localized edge points**: Edges should be close to true edges.
  - **Single edge point response**: Each edge should be detected only once.
- **Mathematical Foundation:**
  - In 1-D, the first derivative of the Gaussian is an optimal edge detector.
  - In 2-D, the image is convolved with a Gaussian, and the gradient is computed.
- **Why Gaussian and Gradient?**
  - Gaussian smoothing reduces noise while preserving edges.
  - The gradient identifies regions of intensity change (edges).
  - The gradient provides edge strength and direction.

The Four Steps in Canny Edge Detection

1. Gaussian Smoothing
2. Gradient Computation
3. Non-Maximum Suppression
4. Hysteresis Thresholding

Step 1: Gaussian Smoothing

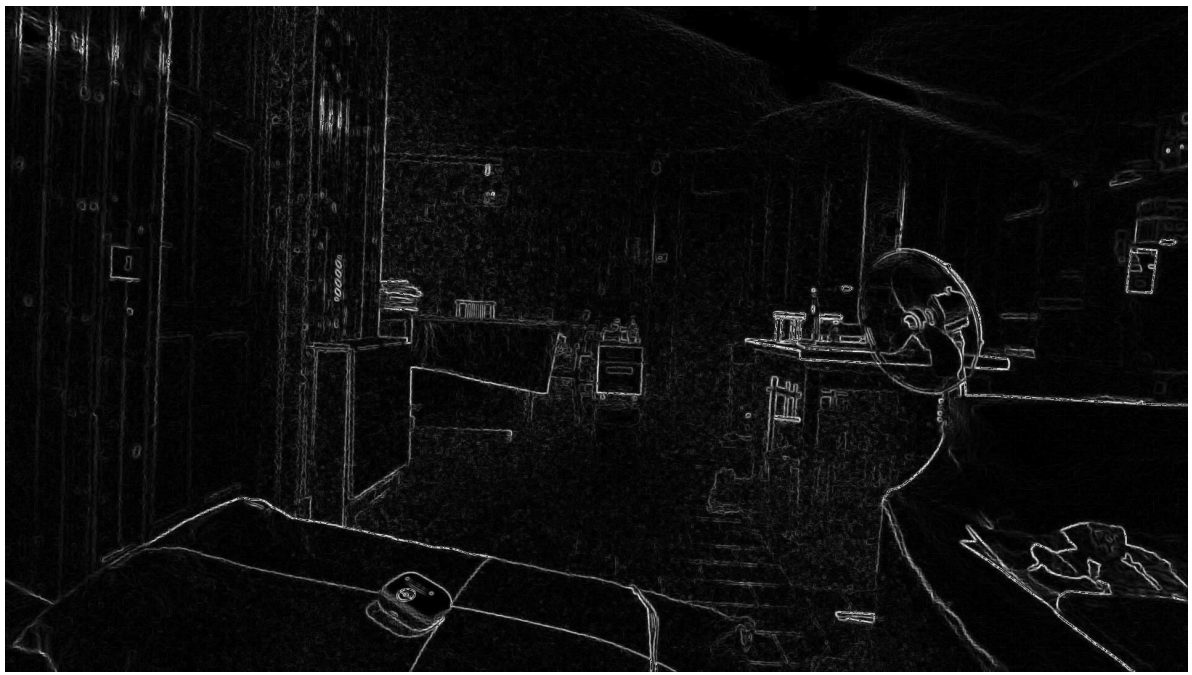
- Purpose: Reduce noise in the image.
- How: Apply a Gaussian filter to smooth the image. The kernel used is a 2D convolution with the Gaussian function:

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

Step 2: Gradient Computation

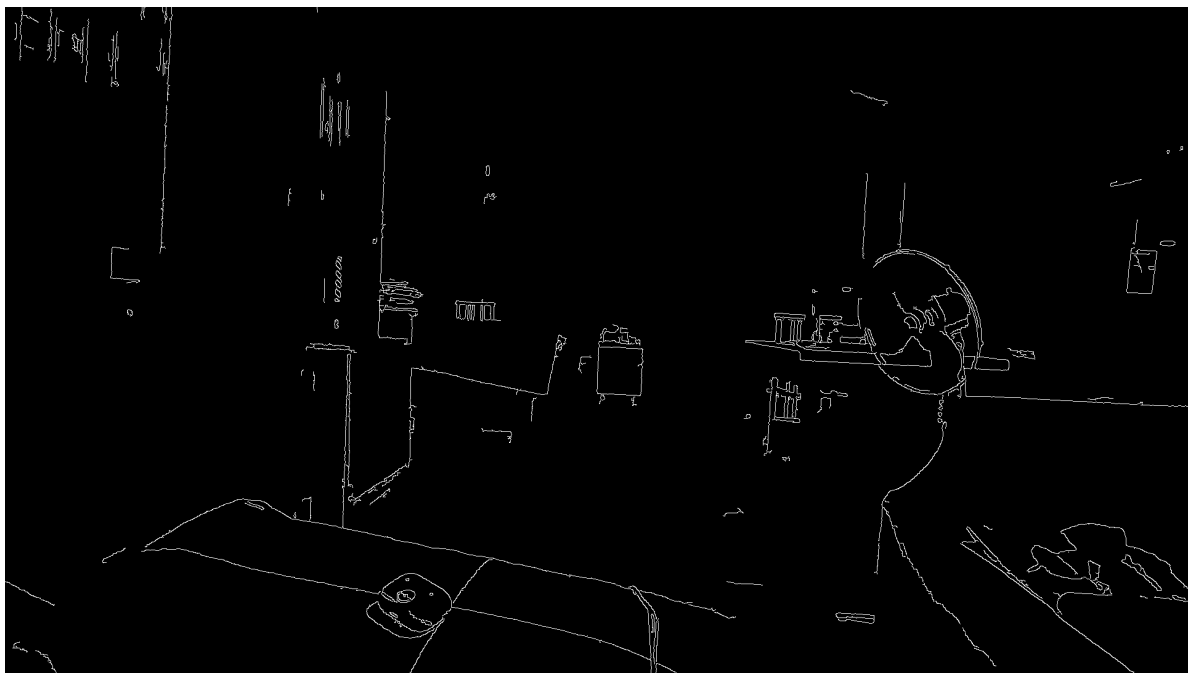
- Purpose: Find areas of intensity change in the image.
- How: Compute the gradient using derivative filters like Sobel operators in the horizontal (Gx) and vertical (Gy) directions.

$$G = \sqrt{G_x^2 + G_y^2}, \quad \theta = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$



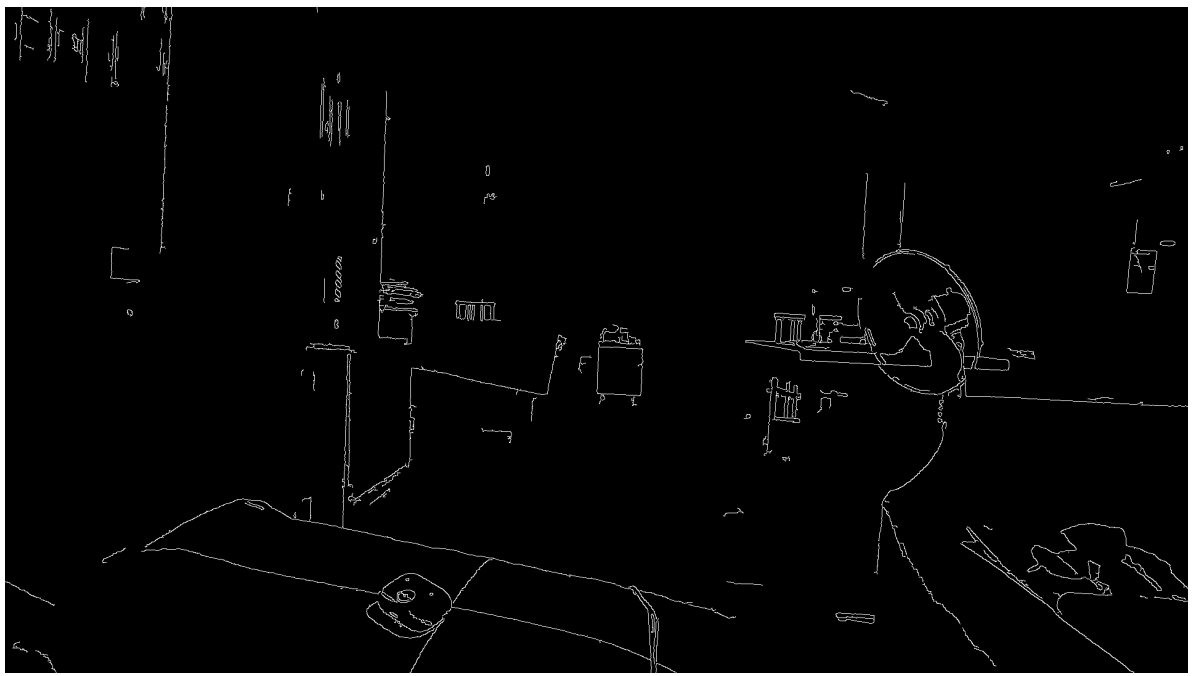
Step 3: Non-Maximum Suppression

- Purpose: Thin the edges.
- How: For each pixel, compare the gradient magnitude with the neighboring pixels in the edge direction. Keep the pixel if it's greater than its neighbors.



Step 4: Hysteresis Thresholding

- Purpose: Finalize the edge map by eliminating weak edges that do not connect to strong edges.
- How: Use two thresholds:
  - Strong edges (above the high threshold) are kept.
  - Weak edges (between the two thresholds) are kept if connected to strong edges.
  - Edges below the low threshold are discarded.



Advantages of Canny Edge Detection

- Good localization of edges.
- Detection of true edges, minimizing false positives.
- Noise resilience due to Gaussian smoothing.

Applications of Canny Edge Detection

- Image Segmentation: Divides images into regions based on edges.
- Object Detection: Useful in computer vision for identifying and tracking objects.
- Medical Imaging: Detecting structures in medical scans like CT and MRI.
- Autonomous Vehicles: Identifying lane boundaries and obstacles.