Mini Project: Edge Detection and Contour Analysis

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1. Introduction

This project implements edge detection using gradient-based methods and extends it with contour extraction and shape analysis. The goal is to detect object boundaries and compute geometric descriptors such as perimeter, area, and compactness.

2. Preprocessing

Convert RGB image to grayscale:

$$I(x, y) = 0.299R + 0.587G + 0.114B$$

Apply Gaussian smoothing:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \quad I_s(x, y) = I(x, y) * G(x, y)$$

3. Edge Detection

Sobel kernels:

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

Gradients:

$$I_x = I_s * G_x, \quad I_y = I_s * G_y$$

Magnitude and direction:

$$M(x, y) = \sqrt{I_x^2 + I_y^2}, \quad \theta(x, y) = \arctan\left(\frac{I_y}{I_x}\right)$$

Thresholding:

$$E(x, y) = \begin{cases} 1 & M(x, y) > T \\ 0 & \text{otherwise} \end{cases}$$

4. Contour Extraction

Contours are sequences of connected edge pixels:

$$C = \{(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\}$$

5. Contour Analysis

Perimeter

$$P = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

Area (Shoelace Formula)

$$A = \frac{1}{2} \left| \sum_{i=1}^{n} (x_i y_{i+1} - x_{i+1} y_i) \right|$$

Compactness

$$C = \frac{P^2}{4\pi A}$$

Moments

$$M_{pq} = \sum_x \sum_y x^p y^q f(x, y)$$

Centroid:

$$\bar{x} = \frac{M_{10}}{M_{00}}, \quad \bar{y} = \frac{M_{01}}{M_{00}}$$

6. Conclusion

This pipeline demonstrates how mathematical transformations can be combined to detect edges, extract contours, and analyze shapes. It provides a foundation for applications in object recognition, biomedical imaging, and computer vision.