Al-Mustaqbal University
College of Science
Fourth stage
Medical Physical Department

جامعة المستقبل
AL MUSTAQBAL UNIVERSITY

Medical Image Analysis

Point, Line, and Edge Detection, Line Detection Using the Hough Transform, Thresholding Image Segmentation

By

Asst. Prof. Dr. Mehdi Ebady Manaa

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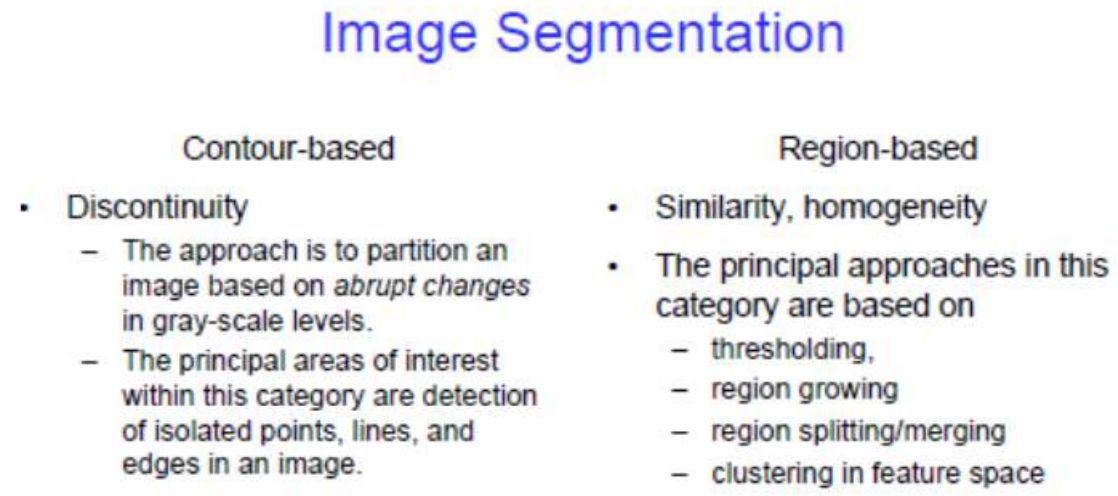
1. Image Segmentation

Segmentation is to subdivide an image into its component regions or objects. Segmentation should stop when the objects of interest in an application have been isolated. Most of the segmentation algorithms in this lecture are based on one of two basic properties of image intensity values: ***discontinuity and similarity.*** In the first category, *the approach is to partition an image into regions based on abrupt changes in intensity*, such as edges. *Approaches in the second category are based on partitioning an image into regions that are similar according to a set of predefined criteria.* . Thresholding, region growing, and region splitting and merging are examples of methods in this category. We show that improvements in segmentation performance can be achieved by combining methods from distinct categories, such as techniques in which edge detection is combined with thresholding.



Examples

Obtain a compact representation of the image to be used for further processing.

Group together similar pixels

Image intensity is not sufficient to perform *semantic* segmentation

- Object recognition
  - Decompose objects to simple tokens (line segments, spots, corners)
- Finding buildings in images
  - Fit polygons and determine surface orientations.
- Video summarization
  - Shot detection

2. Point, Line, and Edge Detection

The focus of this section *is on segmentation methods that are based on detecting sharp, local changes in intensity.* The three types of image characteristics in which we are interested are *isolated points, lines, and edges*. Edge pixels are pixels at which the intensity of an image changes abruptly, and edges (or edge segments) are sets of connected edge pixels. Edge detectors are local image processing tools designed to detect edge pixels. A line may be viewed as a (typically) thin edge segment in which the intensity of the background on either side of the line is either much higher or much lower than the intensity of the line pixels. In fact, as we will discuss later, lines give rise to so-called "roof edges." Finally, an *isolated point* may be viewed as a foreground (background) pixel surrounded by background (foreground) pixels.

There are many types of image segmentation strategies

Segmentation strategy

Edge-based

- Assumption: different objects are separated by edges (grey level discontinuities)
- The segmentation is performed by identifying the grey level gradients
- The same approach can be extended to color channels

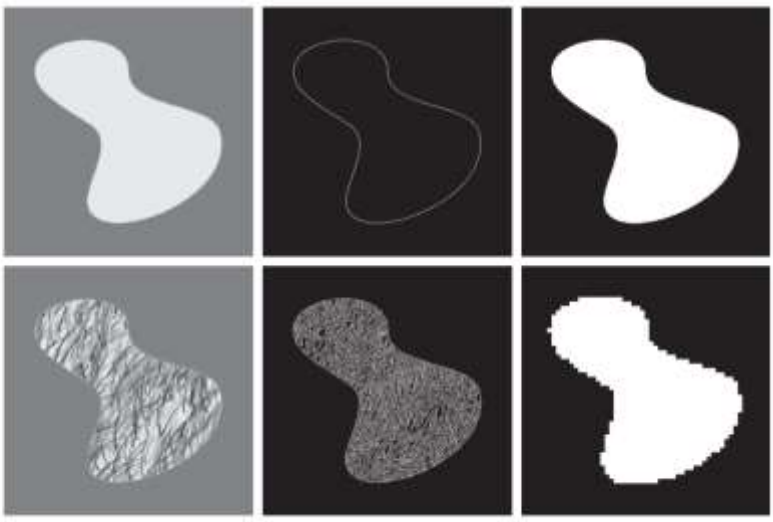
Region-based

- Assumption: different objects are separated by other kind of perceptual boundaries
  - neighborhood features
- Most often texture-based
  - Textures are considered as instantiations of underlying stochastic processes and analyzed under the assumptions that stationarity and ergodicity hold
- Method
  - Region-based features are extracted and used to define "classes"

Goal: separate an image into "coherent" regions.

- Basic methods
  - point, line, edge detection
  - thresholding
  - region growing
  - morphological watersheds
- Advanced methods
  - clustering
  - model fitting.
  - probabilistic methods.
  - …

Segmentation algorithms generally are based on one of 2 basis properties of intensity values: ***discontinuity*** : to partition an image based on sharp changes in intensity. ***similarity*** : to partition an image into regions that are similar according to a set of predefined criteria.



a b c
d e f

FIGURE 10.1
(a) Image of a constant intensity region. (b) Boundary based on intensity discontinuities. (c) Result of segmentation. (d) Image of a texture region. (e) Result of intensity discontinuity computations (note the large number of small edges). (f) Result of segmentation based on region properties.

3. Derivative

It is necessary to use derivative (first and second) in order to discover discontinuities. If we observe a line within an image we can consider it as a one-dimensional function f(x). we will now define the first derivative simply as the difference between two adjacent pixels.

$$\frac{\partial f}{\partial x} = f'(x) = f(x+1) - f(x)$$

$$\frac{\partial^2 f}{\partial x^2} = f''(x) = f(x+1) - 2f(x) + f(x-1)$$

First derivative generally produce **thicker edge** in an image. Second derivative has a **very strong response to find details and noise. Second derivative sign can be used to determine the transition direction.**

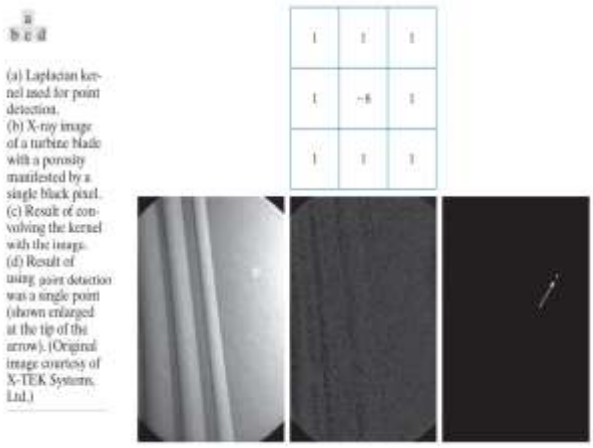
3.1 . Detection of isolated point

Based on the fact that *a second order derivative* is very sensitive to sudden changes we will use it to detect an isolated point. We will use a Laplacian which is the second order derivative over a two dimensional function.

$$\nabla^2 f(x,y) = f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1) - 4f(x,y)$$

The mask for the Laplacian is

0	-1	0
-1	4	-1
0	-1	0



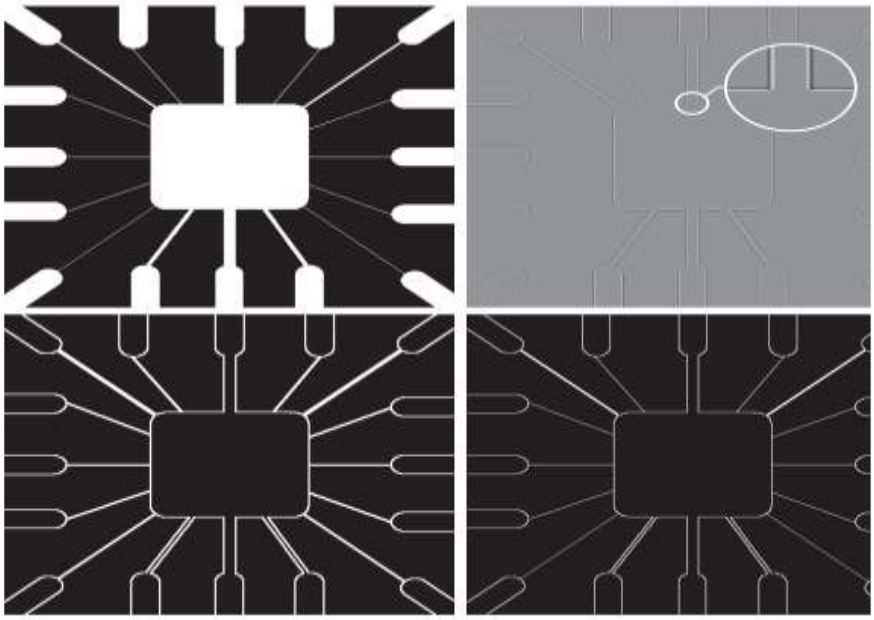
(a) Laplacian kernel used for point detection. (b) X-ray image of a turbine blade with a porosity manifested by a single black pixel. (c) Result of convolving the kernel with the image. (d) Result of using point detection was a single point (shown enlarged at the tip of the arrow). (Original image courtesy of X-TEK Systems, Ltd.)

3.2. Line Detection

We can use the *Laplacian also for detection of line*, since it is sensitive to sudden changes and thin lines. We must note that since the second derivative changes its sign on a line it creates a "double line effect" and it must be handled. Second derivative can have negative results and we need to scale the results. Because the Laplacian image contains negative values, scaling is necessary for display. As the magnified section shows, mid gray represents zero, darker shades of gray represent negative values, and lighter shades are positive. The double-line effect is clearly visible in the magnified region.

a b
c d

(a) Original image.
(b) Laplacian image; the magnified section shows the positive/negative double-line effect characteristic of the Laplacian.
(c) Absolute value of the Laplacian.
(d) Positive values of the Laplacian.



The Laplacian is isotropic متماثل, i.e. independent of direction. If we would like to detect lines on a certain direction only we might want to use masks that would emphasize a certain direction and be less sensitive to other directions.

−1	−1	−1	2	−1	−1	−1	2	−1	−1	−1	
2	2	2	−1	2	−1	−1	2	−1	−1	2	1
−1	−1	−1	−1	−1	2	−1	2	−1	2	−1	1

Horizontal +45° Vertical −45°

a b c d

Line detection kernels. Detection angles are with respect to the axis system with pos
angles measured counterclockwise with respect to the (vertical) *x*-axis.

3.3. Edge models

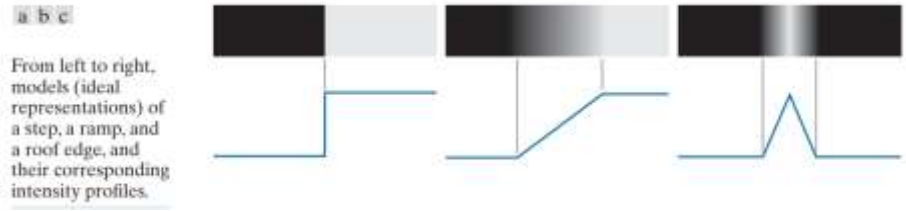
Ideally, edges should be 1 pixel thin. In practice, they are blurred and noisy.

3 different edge types are observed:

- ***Step edge*** حافة الخطوة–Transition of intensity level over 1 pixel

only in ideal, or few pixels on a more practical use

- ***Ramp edge*** حافة المنحدر–A slow and graduate transition
- ***Roof edge*** حافة السقف –A transition to a different intensity and back. Some kind of spread line



a b c

From left to right, models (ideal representations) of a step, a ramp, and a roof edge, and their corresponding intensity profiles.

With gradient operators, we can use as an example two operators

Sobel Vs. Prewitt

Prewitt	Sobel
Simpler to implement	Better noise suppression (smoothing)
Give isotropic results only for vertical and horizontal edges	Give isotropic results only for vertical and horizontal edges
	Preferred because noise suppression is an important issue when dealing with derivatives .

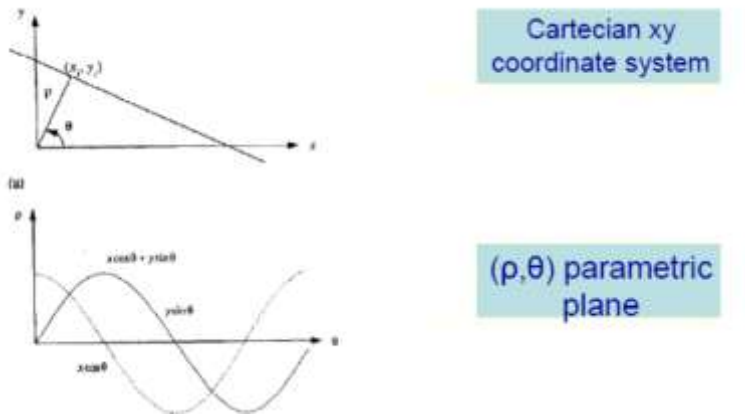
3.3 Edge Linking

Ideally, edge detection should yield sets of pixels lying only on edges. In practice, these pixels seldom characterize edges completely because of occlusions, non-uniform illumination, noise and breaks in the edges. Therefore, edge detection typically is followed by linking algorithms designed to assemble edge pixels into meaningful edges and/or region boundaries. Edge linking may be:

- **Local**: requiring knowledge of edge points in a small neighborhood.
- **Regional**: requiring knowledge of edge points on the boundary of a region.

- **Global**: the Hough transform, involving the entire edge image

The Hough transform is a technique which can be used to isolate features of a particular shape within an image. Hough transform is most commonly used for the detection of regular curves such as lines, circles, ellipses, etc. The main advantage of the Hough transform technique is that it is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise. It maps a straight line $y=mx+c$ in a Cartesian coordinate system into a single point in the (ρ,θ) plane or $\rho=x\cos\theta+y\sin\theta$ For a point (x,y) in the Cartesian coordinate plane , there will be an infinite number of curves in the (ρ,θ) plane.

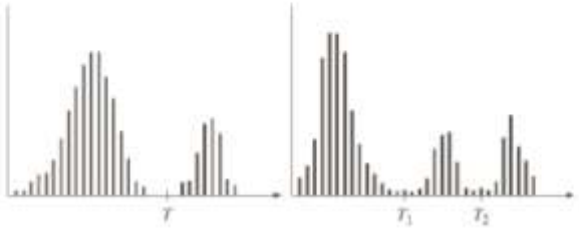


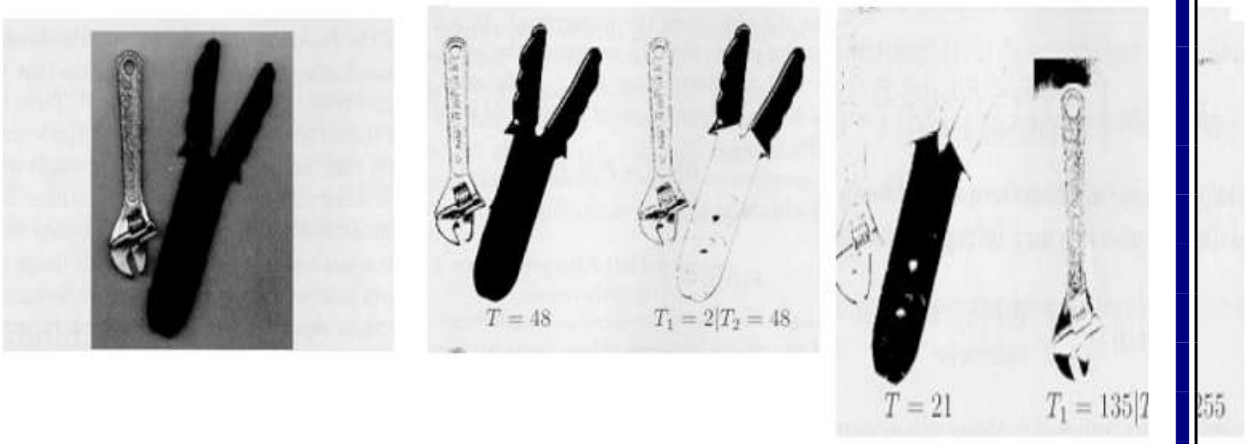
When two points (xi,yi) and (xj,yj) lie on the same straight line , the curves in the (ρ,θ) plane which correspond, respectively , to the two points (xi,yi) and (xj,yj) in the Cartesian plane will intersect at a point. This intersection point determines the parameter of the line that joins these two points Similar arguments apply for the three collinear points. This property between Cartesian plane and the parametric plane will be useful in finding the line that fits points in the xy plane.

4. Thresholding

Image partitioning into regions directly from their intensity values.

$$g(x,y)=\begin{cases}1 & \text{if } f(x,y)>T\\ 0 & \text{if } f(x,y)\le T\end{cases} \qquad g(x,y)=\begin{cases}0 & \text{if } f(x,y)\le T_1\\ 1 & \text{if } T_1<f(x,y)\le T_2\\ 2 & \text{if } f(x,y)>T_2\end{cases}$$





Basic Global Thresholding Algorithm

- Select initial threshold estimate T.
- Segment the image using T Region G1 (values > T) and region G2 (values < T).
- Compute the average intensities m1 and m2 of regions G1 and G2 respectively. Set T= (m1+m2)/2 Repeat until the change of T in successive iterations is less than ΔT.

Multiple-Choice Questions (MCQs):

1. What is the primary goal of image segmentation in the context of medical image analysis?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To subdivide an image into its component regions or objects.
- D) To amplify background intensity.
- E) To eliminate abrupt changes in intensity.

Correct Answer: C) To subdivide an image into its component regions or objects.

2. What are the two basic properties of image intensity values used in segmentation algorithms?

- A) Brightness and contrast.
- B) Discontinuity and similarity.
- C) Saturation and hue.
- D) Red and green channels.
- E) Transparency and opacity.

Correct Answer: B) Discontinuity and similarity.

3. In image segmentation, which method is based on detecting sharp, local changes in intensity?

- A) Region growing.
- B) Edge linking.
- C) Thresholding.
- D) Region splitting and merging.
- E) Derivative-based segmentation.

Correct Answer: E) Derivative-based segmentation.

4. What is the purpose of using derivatives (first and second) in

image analysis, specifically in detecting discontinuities?

- A) To enhance image intensity.
- B) To amplify background intensity.
- C) To blur the image for better visualization.
- D) To discover abrupt changes in intensity.
- E) To reduce noise in the image.

Correct Answer: D) To discover abrupt changes in intensity.

5. Which type of edge model ideally represents edges as 1 pixel thin?

- A) Ramp edge.
- B) Roof edge.
- C) Step edge.
- D) Gradual edge.
- E) Circular edge.

Correct Answer: C) Step edge.

6. What is the primary purpose of edge linking in image analysis after edge detection?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To assemble edge pixels into meaningful edges and/or region boundaries.
- D) To eliminate isolated points.
- E) To reduce noise in the image.

Correct Answer: C) To assemble edge pixels into meaningful edges and/or region boundaries.

7. Which type of edge linking requires knowledge of edge points in a small neighborhood?

- A) Local edge linking.
- B) Regional edge linking.
- C) Global edge linking.
- D) Derivative-based edge linking.
- E) Threshold-based edge linking.

Correct Answer: A) Local edge linking.

8. What is the primary advantage of the Hough transform in image analysis?

- A) It enhances image intensity.
- B) It is tolerant of gaps in feature boundary descriptions.
- C) It blurs the image for better visualization.
- D) It eliminates abrupt changes in intensity.
- E) It reduces noise in the image.

Correct Answer: B) It is tolerant of gaps in feature boundary descriptions.

9. In the Hough transform, how is a straight line represented in the parametric plane?

- A) $y = mx + c$.
- B) $x = my + c$.
- C) $\rho = x\cos\theta + y\sin\theta$.
- D) $\rho = x\cot\theta + y$.
- E) $\theta = x\tan\rho + y$.

Correct Answer: C) $\rho = x\cos\theta + y\sin\theta$.

10. What is the purpose of thresholding in image partitioning?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To amplify background intensity.

- D) To segment the image directly from intensity values.
- E) To detect isolated points.

Correct Answer: D) To segment the image directly from intensity values.