Chapter 7. Image Segmentation

Ch.1~3 : background

Ch.4~6 : image processing tech.

Ch.7~9 : image analysis

Techniques for extracting information from an image

- Image segmentation
  - image $\xrightarrow{subdivide}$ its constituent parts or objects
  - isolate object of interest

  ex) Autonomous air-to-ground target acquisition application

    - image $\xrightarrow{seg.}$ road $\xrightarrow{seg.}$ vehicle

- Segmentation algorithm for mono. images
  - based on one of two basic properties of gray-level values : *discontinuity and similarity*

  - discontinuity
    - ✓ to partition an image based on abrupt changes in gray level
    - ✓ detection of isolated points, lines and edges in image
  - similarity
    - ✓ based on thresholding , region growing, and region splitting and merging
  - applicable to both static and dynamic images
  - motion : can be used as a powerful cue to improve the performance of segmentation algorithms

7.1 Detection of Discontinuities

- points, lines, edges : detected
- procedure

  3× 3 mask

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

- $$R = \sum_{i=0}^{9} w_i z_i$$

  where z_i : gray level of pixel associated with mask coeff. w_i

- response of mask : defined with its center location

7.1.1 Point Detection

–1	–1	–1
–1	8	–1
–1	–1	–1

- if $|R| > T$, isolated point : detected

  where T : nonnegative threshold

  - weighted difference between the center point and its neighbor

7.1.2 Line Detection

–1	–1	–1
2	2	2
–1	–1	–1

Horizontal

–1	–1	2
–1	2	–1
2	–1	–1

+ 45°

–1	2	–1
–1	2	–1
–1	2	–1

Vertical

2	–1	–1
–1	2	–1
–1	–1	2

–45°

- the first mask
  - respond more strongly to lines (one pixel thick) oriented horizontally
  - second : +45˚
  - third : vertical
  - fourth : –45˚

- R_1, R_2, R_3, R_4 : responses of four masks
  - if $|R_i| > |R_j|$ for all $j \neq i$

    → that point : more likely associated with a line in direction of mask

    ex.) $|R_i| > |R_j|$ j=2,3,4 → Horizontal line

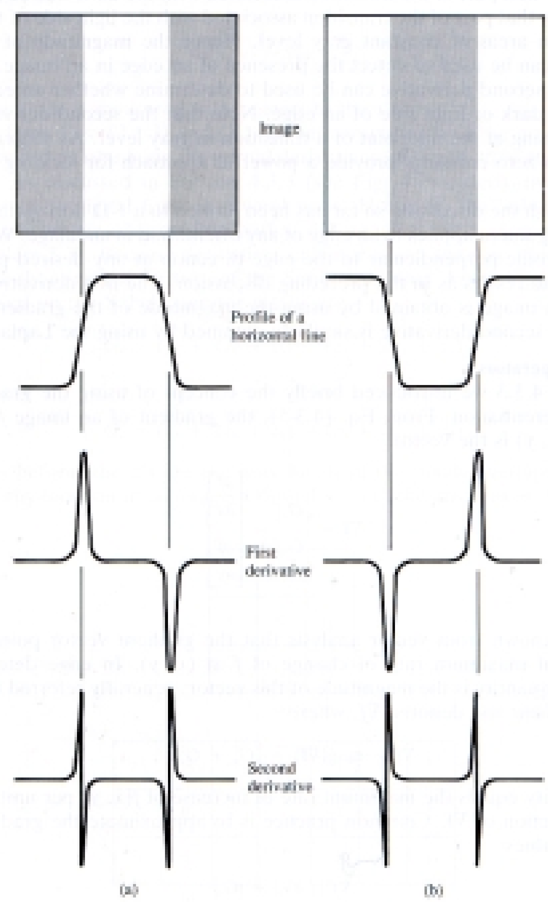
7.1.3 Edge Detection

- isolated points, thin lines
  - not frequent occurrences in most practical application
- edge detection
  - the most common approach for detecting meaningful discontinuities in gray level

1) Basic formulation

- Edge : the boundary between two regions with relatively distinct gray-level properties

- basic idea
  - computation of local derivative operator



- ✓ light strip on dark background
- ✓ edge : smooth change of gray level

  (blurred as a result of sampling)
- ✓ first derivative

  : positive at the leading edge of transition

  : negative at the trailing edge of transition

  : zero in areas of constraint gray level
- ✓ second derivative

  : positive for dark side

  : negative for light side

  : zero in constant area
- ✓ magnitude of first derivative

  : used to detect the presence of a edge
- ✓ sign of second derivative

  : used to determine whether an edge pixel lies on the dark or light side of edge

  : zero crossing at the midpoint of a transition in gray level

- applied to an edge of any orientation
  - define a profile perpendicular to the edge direction at any desired point
- first derivative at any point
  - obtained by using the magnitude of gradient
- second derivative at any point
  - obtained by using the Laplacian

2) Gradient operators

- Gradient of image f(x,y) at location (x,y)
  - Vector

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

  : points in the direction of max. rate of change of f at (x,y)

  - Magnitude

$$\nabla f = mag(\nabla \mathbf{f}) = \left[G_x^2 + G_y^2\right]^{1/2}$$

  : max. rate of increase of f(x,y) per unit distance in the direction of $\nabla \mathbf{f}$

  - appr.

$$\nabla f \approx |G_x| + |G_y|$$: much simpler to implement

  - direction

$$\alpha(x,y) = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$

  - Sobel operator
    - ✓ Differencing and smoothing effect

Noise reduction effect

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

(a)

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

(b)

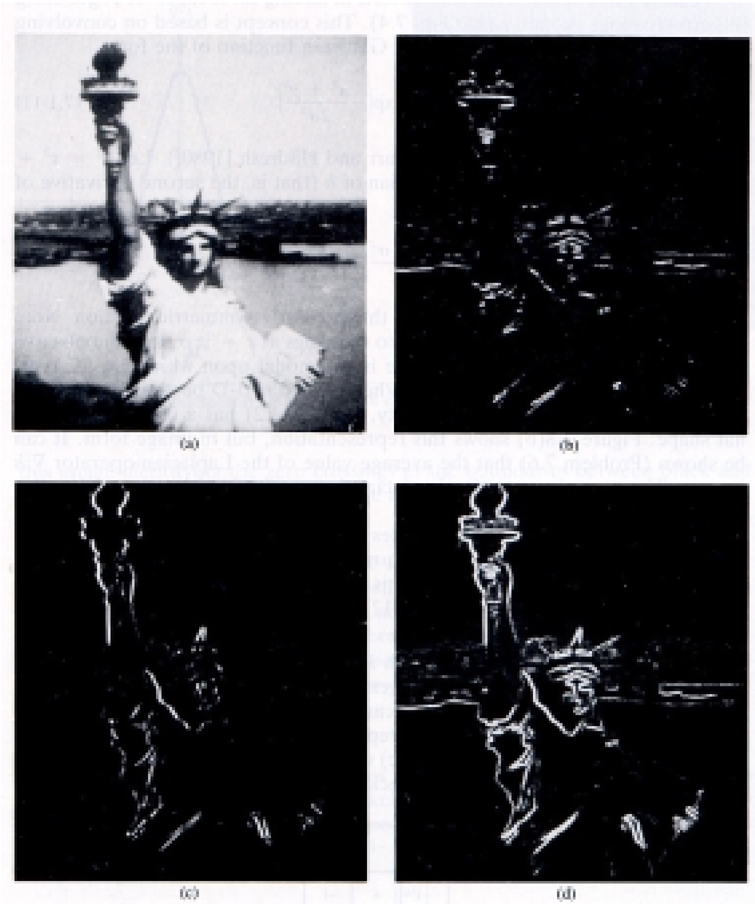
-1	0	1
-2	0	2
-1	0	1

(c)

$$G_x = (Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3)$$

$$G_y = (Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7)$$

ex.)



(a) original image

(b) $|G_x|$: horizontal derivative

(c) $|G_y|$: vertical derivative

(d) complete gradient image obtained by using Eg. 7.5-5

3) Laplacian

- $\nabla^2 f = \dfrac{\partial^2 f}{\partial x^2} + \dfrac{\partial^2 f}{\partial y^2}$
- the form most frequently encountered in practice

- $\nabla^2 f = 4z_5 - (z_2 + z_4 + z_6 + z_8)$
- center coeffs. : positive
- outer coeffs. : negative
- sum of coeffs. : zero

0	−1	0
−1	4	−1
0	−1	0

- responds to transitions in intensity

● Laplacian : seldom used in practice for edge detection
- unacceptively sensitive to noise
- produce double edges
- unable to detect edge direction
- the secondary role of detector

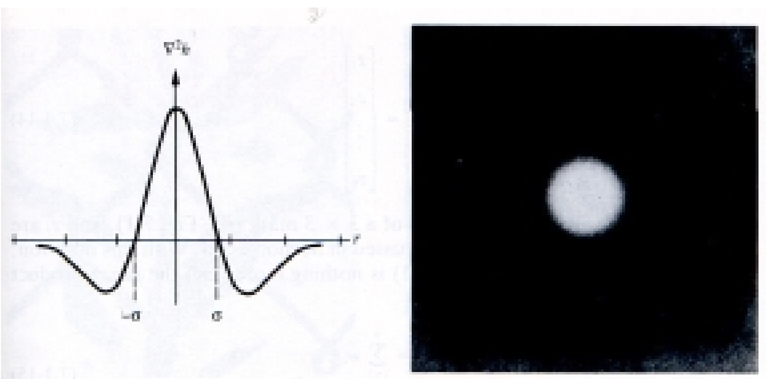
  : for establishing whether a pixel is an the dark or light side of an edge

● More general use of Laplacian : finding location of edge
- use of zero-crossing property
- convolution of image with Laplacian of 2-D Gaussian function of the form

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

  where σ : standard deviation
- Laplacian of h

$$\nabla^2 h = \left(\frac{r^2 - \sigma^2}{\sigma^4}\right)\exp\left(-\frac{r^2}{2\sigma^2}\right) \qquad \text{where } r^2 = x^2 + y^2$$



(a) (b)

- zero crossing at $r = \pm\sigma$
- Laplacian image obtained by convoluting this operator with a given image → image blurring

(※ 원영상과 $\nabla^2 h$를 convolution 하면 영상이 blurring 되면서 edge 에서 zero crossing 이 발생한다. 즉, black 은 negative, light 는 positive, 중간은 zero 값으로 된다.)

ex.)

- Edge detection
  - gradient operation
  - for image with shape transition and low noise
- Zero crossing method
  - for image with blurring and high noise
  - disadvantage

    : computational complexity and time

7.2 Edge Linking and Boundary Detection

- edge detection tech.
  - seldom characterizes a boundary completely because of noise, break in boundary from nonuniform discontinuities, and other effects (spurious intensity discontinuities)

- followed by edge linking and other boundary detection tech.

7.2.1 Local Processing

- analyzing the char. of pixels in a small neighborhood (3x3 or 5x5)
  - similar points : linked, forming a boundary of pixels with common properties
- two principal properties

  1) strength of response of gradient operator

  2) direction of gradient

  - similar magnitude

    $$|\nabla f(x,y) - \nabla f(x',y')| \le T$$

  - similar direction

    $$|\nabla \alpha(x,y) - \nabla \alpha(x',y')| < A$$

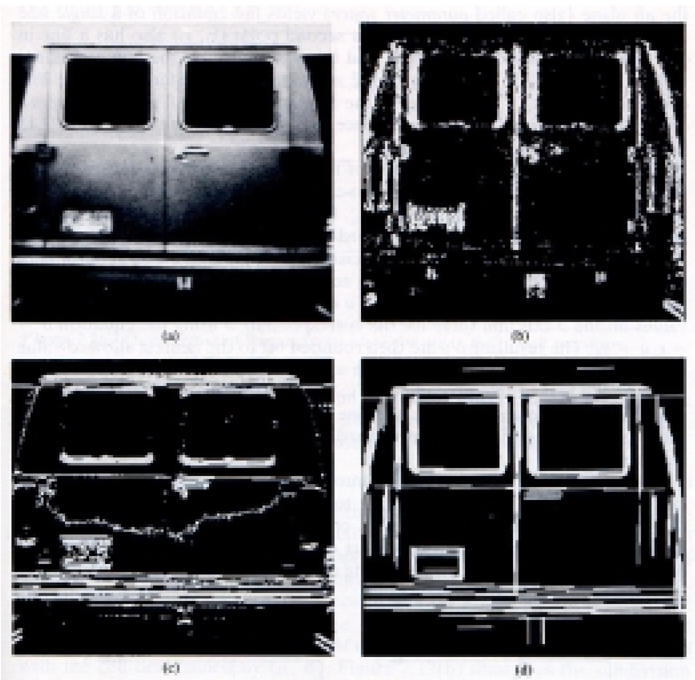
    threshold

  - if magnitude and direction criteria : satisfied

    → two points : linked

  - repeated for every location in image
- record for linked points
  - assign a different gray level to each set of linked edge pixels

  ex.)



7.2.2 Global Processing via the Hough Transform

- linking points
  - determining whether they lie on a curve of specified shape
  - use of global relationships between pixels
- alternative approach by Hough : Hough transform
  - a point : (x_i, y_i)
  - eq. of straight line : $y_i = ax_i + b$
  - in ab-plane (called *parameter space*)

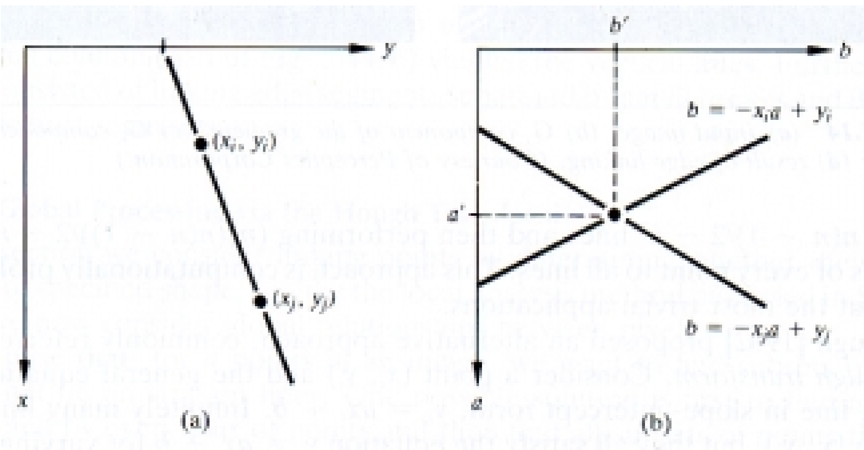
    $b = -x_i a + y_i$

    : eq. single line for a fixed pair (x_i, y_i)
  - a second point : (x_j, y_j)

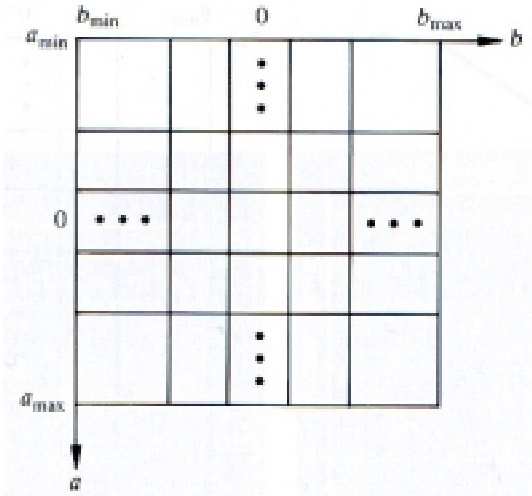
    $b = -x_j a + y_j$
  - at (a', b')

    are line intercepts the other

    where a' : slope, b' : intercept



  - accumulator cells



- ✓ $(a_{amx}, a_{\min}), (b_{amx}, b_{\min})$

  : expected ranges of slope and intercept value

- ✓ the cell at coordinates (i, j), with accumulator value $A(i, j)$

  : corresponds to square associated with parameter space coordinates (a_i, b_j)

- ✓ initially, cells=0 (i.e. $A(i, j) = 0$)

- ✓ for every points (x_k, y_k)

  : for each of the allowed subdivision values on the a axis

  → solve $b = -x_k a + y_k$

  Rounded off to the nearest allowed value in the b axis

  : if a choice of a_p results in b_q

  → $A(p,q) = A(p,q) + 1$

- ✓ a value of M in $A(i, j)$

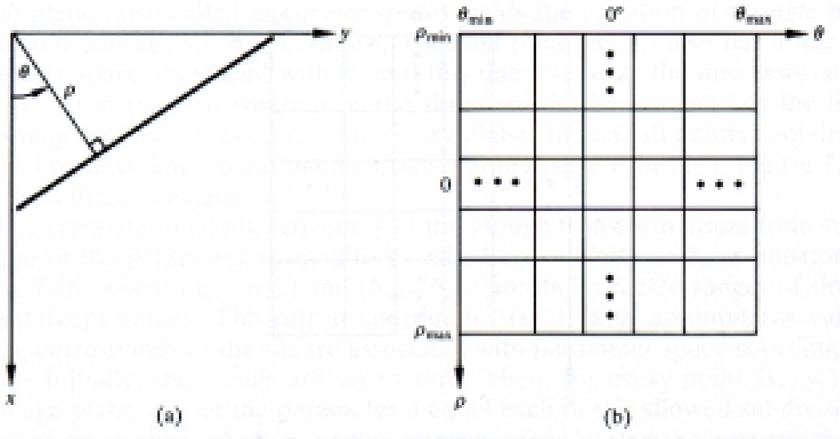
  : corresponds to M points in the xy plane lying on the line $y = a_i x + b_i$

- ✓ accuracy : determined by the no. of subdivision in ab plane

- problem
  - ✓ for vertical line

    a, b : approach infinity

- normal representation of line
  - ✓ $x\cos\theta + y\sin\theta = \rho$



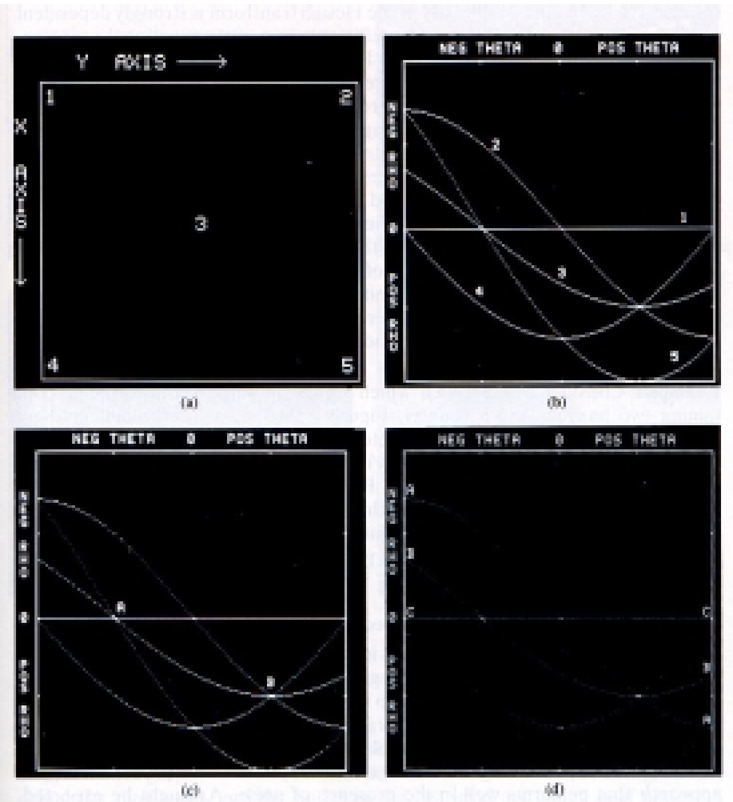
  - ✓ loci : sinusoidal curve in $\rho\theta$ plane
  - ✓ range of angle $\theta = \pm 90^{\circ}$, measured with the x axis

    horizontal line $\theta = 0^{\circ}$, with $\rho = positive$ x intercept

    vertical line $\theta = 90^{\circ}$, with $\rho = positive$ y intercept

    $\theta = -90^{\circ}$, with $\rho = negative$ y intercept

ex.)



- general form $g(\mathbf{v},\mathbf{c})=0$

  where $\mathbf{v}$: vector of coordinate

  $\mathbf{c}$: vector of coefficient

  ex.) the points lying on the circle

  $$(x-c_1)^2+(y-c_2)^2=c_3^2$$

  ✓ 3-D parameter space c_1, c_2, c_3

  accumulator $A(i,j,k)$