Image Processing: Edge and Contours

Introductions

- Edge and contour has an important role in human vision. It help us to understand the virtually shape of any object, understand the boundary and reconstruct a complete figure.

Gradient – base detection

- The figure 6.1 is the basically example to describe ‘EDGE’. Follow the figure, image (a) is a gray circle in black background, and image (b) is an intensity profile of (a). From mathematics principle, first derivative give a slope. In this case, slope of intensity profile is boundary of image or *‘edge’*.

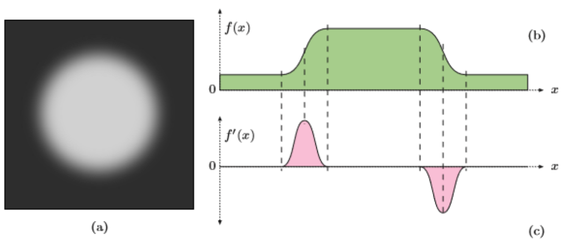

Figure 6.1

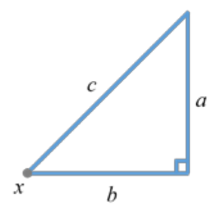

Figure 6.2

- In continuous case, $f'(x)$ = slope of tangent x = slope of line c
- In discreet case, $f'(u)$ = slope of neighbor values = $\frac{f(u+1)-f(u-1)}{(u+1)-(u-1)} = \frac{f(u+1)-f(u-1)}{2}$

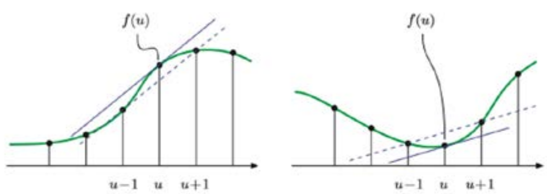

Figure 6.3

- Figure 6.3 show the different between discrete and continuous case. The green line is continuous case, the derivative is the slope of tangent line of the point. The point is discrete case, the derivative is the slope of estimate dashed line.
- Partial derivative and the gradient is derivative of the multi variable function, for example,

$$f'(u,v) = \frac{\partial f(u,v)}{\partial x}, \frac{\partial f(u,v)}{\partial y}$$

- Gradient vector; $\nabla I(u,v) = \begin{bmatrix} \frac{\partial I(u,v)}{\partial u} \\ \frac{\partial I(u,v)}{\partial v} \end{bmatrix}$, gradient vector always be perpendicular with edge line

- Magnitude of gradient; $|\nabla I| = \sqrt{(\frac{\partial I(u,v)}{\partial u})^2 + (\frac{\partial I(u,v)}{\partial v})^2}$, magnitude of gradient is basis of edge detection methods
- Derivative filter
  - Apply linear filter in each dimension to $I'(u,v)$

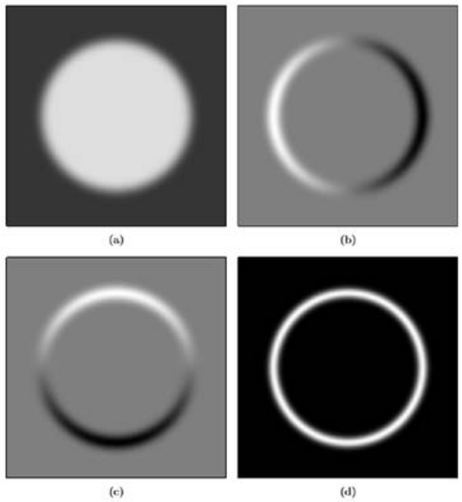

Figure 6.4

(a) *synthesis image*
(b) *horizontal direction, I'(u,v)*[-0.5 0 0.5]*
(c) *vertical direction,* $I'(u,v)*\begin{bmatrix}-0.5\\0\\0.5\end{bmatrix}$
(d) *magnitude of gradient,* $|\nabla I|$

Edge operators

- Prewitt and Sobel operators
  - These two operator are classic methods to differ only margin
  - It are linear filter that extend over 3 adjacent row and column
  - Prewitt operator
    - $H_x^P = \begin{bmatrix}-1 & 0 & 1\\-1 & 0 & 1\\-1 & 0 & 1\end{bmatrix}$ $\quad H_y^P = \begin{bmatrix}-1 & -1 & -1\\0 & 0 & 0\\1 & 1 & 1\end{bmatrix}$
  - Sobel operator
    - $H_x^S = \begin{bmatrix}-1 & 0 & 1\\-2 & 0 & 2\\-1 & 0 & 1\end{bmatrix}$ $\quad H_y^S = \begin{bmatrix}-1 & -2 & -1\\0 & 0 & 0\\1 & 2 & 1\end{bmatrix}$
  - Estimate for local gradient
    - Prewitt operator, $\nabla I = \frac{1}{6}\begin{bmatrix}I * H_x\\I * H_y\end{bmatrix}$
    - Sobel operator, $\nabla I = \frac{1}{8}\begin{bmatrix}I * H_x\\I * H_y\end{bmatrix}$
  - Edge strength and orientation
    - Assume D is result from filtering = H*I

- Local edge strength; $E(u,v) = \sqrt{D_x^2 + D_y^2}$
- Local edge orientation; $\Phi(u,v) = \tan^{-1}(\frac{D_y}{D_x})$

- Robert operator
    - It is small filter 2x2 size
    - This filter is estimation of the directional gradient along the image diagonal.
    - $H_1^R = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \qquad H_2^R = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$
    - This filter response to diagonal edges and does not highly selective to orientation

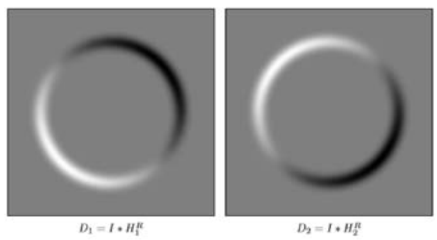

Figure 6.5

- Compass operator
    - Since linear edge filters are orientation-insensitive, output are non-edge structure. Using sets of filter for two direction can solve this problem.
    - Example of the set of filters,

$$H_0^S = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad H_4^S = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix},$$

$$H_1^S = \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix} \qquad H_5^S = \begin{bmatrix} 2 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -2 \end{bmatrix},$$

$$H_2^S = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \qquad H_6^S = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix},$$

$$H_3^S = \begin{bmatrix} 0 & -1 & -2 \\ 1 & 0 & -1 \\ 2 & 1 & 0 \end{bmatrix} \qquad H_7^S = \begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix}.$$

- Kirsch filter

$$H_0^K = \begin{bmatrix} -5 & 3 & 3 \\ -5 & 0 & 3 \\ -5 & 3 & 3 \end{bmatrix} \qquad H_4^K = \begin{bmatrix} 3 & 3 & -5 \\ 3 & 0 & -5 \\ 3 & 3 & -5 \end{bmatrix},$$

$$H_1^K = \begin{bmatrix} -5 & -5 & 3 \\ -5 & 0 & 3 \\ 3 & 3 & 3 \end{bmatrix} \qquad H_5^K = \begin{bmatrix} 3 & 3 & 3 \\ 3 & 0 & -5 \\ 3 & -5 & -5 \end{bmatrix},$$

$$H_2^K = \begin{bmatrix} -5 & -5 & -5 \\ 3 & 0 & 0 \\ 3 & 3 & 3 \end{bmatrix} \qquad H_6^K = \begin{bmatrix} 3 & 3 & 3 \\ 3 & 0 & 3 \\ -5 & -5 & -5 \end{bmatrix},$$

$$H_3^K = \begin{bmatrix} 3 & -5 & -5 \\ 3 & 0 & -5 \\ 3 & 3 & 3 \end{bmatrix} \qquad H_7^K = \begin{bmatrix} 3 & 3 & 3 \\ -5 & 0 & 3 \\ -5 & -5 & 3 \end{bmatrix}.$$

Other edge operators

- Second derivative
  - Follow mathematics principle, if $I''(u,v) = 0$, that point is *EDGE*
  - Since it may amplify noise, you should apply low-pass filter to the system.
  - For example, Laplacian of Gaussian is Gaussian smoothing filter and second derivative.
  - This method is sensitive to visible noise.
- Edge at different scales
  - A typical small edge operators that response only its filter region (mostly 3x3).
  - This operator call multiresolution techniques
- Canny Operator
  - Goal
    - Minimize false edge point

      Step preprocessing with Gaussian filter > Gradient orientation > Threshold > Edge ☺
    - Achieve good localization of edges
    - Deliver only a 'single mark' on each edge
  - Core
    - Gradient method and zero crossing of second derivative for precise edge localization
  - Consist of set of relatively large and orientation filter and merge common result into common edge map.

Edge to Contour

- Contour form itself from a trace of edge.
- Edge map is selection of edge point and apply threshold operator to edge strength deliver.

Edge sharpening

- Edge sharping is a common approach to amplify high frequency image component.
- Edge sharping with 'Laplace filter'
  - Filter base on second derivative of an image function >> rapid intensity change
  - The edge is sharpen by $f(x) = f(x) - \omega f''(x)$, when $\omega \geq 0$
  - Laplace operator, $\nabla^2 f(u,v) = \frac{\partial^2 f}{\partial u^2} + \frac{\partial^2 f}{\partial v^2}$