A Comparative Study of Image Segmentation Using Edge-Based Approach

Rajiv Kumar, Arthanariee A. M.

***Abstract*—**Image segmentation is the process to segment a given image into several parts so that each of these parts present in the image can be further analyzed. There are numerous techniques of image segmentation available in literature. In this paper, authors have been analyzed the edge-based approach for image segmentation. They have been implemented the different edge operators like Prewitt, Sobel, LoG, and Canny on the basis of their threshold parameter. The results of these operators have been shown for various images.

***Keywords*—**Edge Operator, Edge-based Segmentation, Image Segmentation, Matlab 10.4.

I. Introduction

THE image segmentation is the process of dividing an image into different regions such that each region is homogeneous. Image segmentation is the key behind image understanding. A number of image segmentation techniques are available, but none of them are suitable for all the applications. Researchers have been extensively worked over this problem and proposed various methods for image segmentation. Edge-based segmentation is one of the widely used techniques for image segmentation. In edge-based approach, the partitions or sub-division of an image is based on some abrupt changes in the intensity level of images. Reference [1] shows that detecting edges between regions of different average gray level can be applied to detect a wide variety of "texture edges", in which two regions differ with respect to the average value of some local property. Indeed, if one first processes, the picture by computing the value of the local property at each point, the result is a new picture in which the regions now differ in average gray level. The edges of objects in a picture cannot be accurately located in the presence of noise, and therefore an edge detection technique is required which will minimize the errors of determination of edge positions [2].

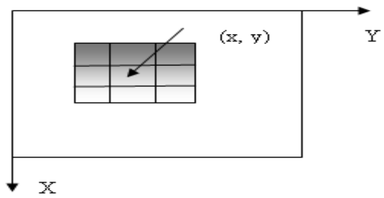
Section II discusses the image segmentation which has been focused on edge-based approach. Under this approach, we analyzed edge detection techniques. A number of operators which are based on first-order derivative and second-order derivative such as Prewitt, Sobel, LoG and Canny have discussed in detail. Section III performs the experimental results and discussion based on these operators. Finally, Section IV concludes the paper by analyzing and comparing the results of these operators.

Rajiv Kumar is with the Research and Development Centre, Bharathiar University, Coimbatore (Tamil Nadu), India (corresponding author; phone: 09991272071; e-mail: dhimanrajiv2000@ yahoo.co.in).

Arthanariee A. M. is with the Department of Science and Humanities, Nehru Institute of Technology, Kaliyapalayam, Coimbatore – 105, India (e-mail: arthanarimsvc@gmail.com).

II. Edge-Based Segmentation

To identify edges in the image, the 3×3 Mask has been taken.



(a)

$W_{-1,-1}$	$W_{-1,0}$	$W_{-1,1}$
$W_{0,-1}$	$W_{0,0}$	$W_{0,1}$
$W_{1,-1}$	$W_{1,0}$	$W_{1,1}$

(b)

Fig. 1 (a) Image (b) 3×3 Mask

$$\boldsymbol{R} = \frac{\sum_{i=-1}^{1}\sum_{i=-1}^{1} W_{i,j}\, f(x+i,y+j)}{N} \qquad (1)$$

where $W_{i,j}$ is the value of mask at location (x, y); f (x, y) is the intensity value at location (x, y); N is the total number of cells in the filter and R is the response of filter at that particular point.

A. Edge Detection

An edge may be loosely defined as a local discontinuity in the pixel values which exceeds a given threshold. It is a boundary between two regions having distinct intensity level. The edges have been used to measure the size of objects in an image; to isolate particular objects from their background; to recognize or classify objects. A common strategy in designing edge operators is to find the filter which optimizes the performance with respect to the three criteria: good detection, good localization, and a unique response to a single edge [7]. Reference [8] described that all points of an edge detected image can be linked via their neighborhoods and formed into a boundary of pixels which share common properties. This linking is accomplished by an analysis of two things;

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1. The strength of the response of the gradient operator used to produce the edge pixel.
2. The direction of the gradient.

The changes of intensity, first-order derivative and second-order derivative have been shown in Fig. 2.

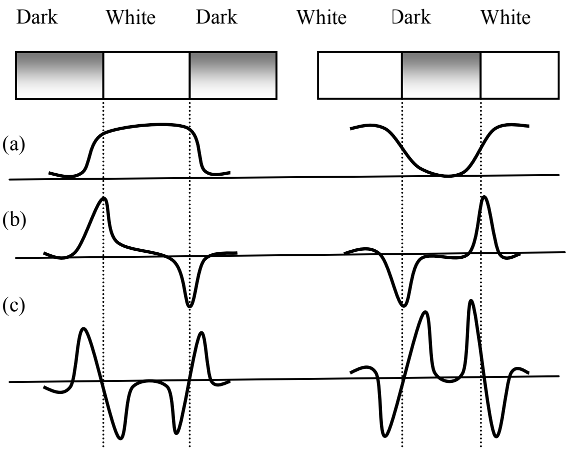

Fig. 2 (a) Intensity profile (b) First-order derivative (c) Second-order derivative

A. First-Order Derivative

First-order derivative responds whenever there is discontinuity in intensity level. It is positive at the leading edge and negative at the trailing edge. The edge operators are based on differentiation; to apply the continuous derivative to a discrete image, we have obtained:

$$\frac{df}{dx} = \lim_{h\to 0}\frac{f(x+h)-f(x)}{h} \quad (2)$$

Since in an image, the smallest possible value of h is 1, being the difference between the index values of two adjacent pixels, a discrete version of the derivative expression is

$$f(x+h) - f(x) \quad (3)$$

For 2D image, we use partial derivatives; gradient vector which is defined by

$$\left[\frac{\partial f}{\partial x}\ \frac{\partial f}{\partial y}\right] \quad (4)$$

The function f (x, y) points in the direction of its greatest increase. The direction of that increase is given by

$$tan^{-\mathbf{1}}\left(\frac{\partial f/\partial y}{\partial f/\partial x}\right) \quad (5)$$

and its magnitude is given by

$$\sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial x}\right)^2} \quad (6)$$

Most edge detection methods have been concerned with finding the magnitude of the gradient, and then applying a threshold to the result. There are several ways to calculate the image gradient:

1. Sobel Edge Operator

The sobel operator is a discrete differentiation operator, computing an approximation of the opposite of the gradient of the image intensity function. At each point in the image, the result of the sobel operator is either the corresponding opposite to the gradient vector or the norm of this vector. The sobel operator is based on convolving the image with a small, separable and integer valued filter in horizontal and vertical direction. The gradient of a 2-D function f(x, y) is defined as the vector

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (7)$$

The sobel edge detector approximate digitally the first derivatives G_x and G_y. It is computed as:

$$G = \sqrt{G_x^2 + G_y^2} \quad (8)$$

$$= \begin{Bmatrix} [(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)]^2 \\ +[(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)]^2 \end{Bmatrix} \quad (9)$$

A pixel at location (x, y) is an edge pixel if G ≥ T at that location where T is a specified threshold.

Z_1	Z_2	Z_3
Z_4	Z_5	Z_6
Z	Z_8	Z_9

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

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

Fig. 3 Masks used for Sobel Edge operator

Let $\alpha(x,y)$ represent the direction angle of the vector ∇f at (x,y). Then

$$\alpha(x,y) = \tan^{-1}\left(\frac{G_y}{G_x}\right) \quad (10)$$

where the angle is measured with respect to the x-axis. The direction of an edge at (x,y) is perpendicular to the direction of the gradient vector at that point.

$$G = \sqrt{G_x^2 + G_y^2} \quad (11)$$

$$= \begin{Bmatrix} [(z_7 + z_8 + z_9) - (z_1 + z_2 + z_3)]^2 \\ +[(z_3 + z_6 + z_9) - (z_1 + z_4 + z_7)]^2 \end{Bmatrix} \quad (12)$$

The mask finds the horizontal edges which are equivalent to gradient in the vertical direction and the mask compute the vertical edges are equivalent to gradient in the horizontal direction. The reason is that the gradient vector points in the direction of maximum rate of change of f at co-ordinate x, y). Therefore, the direction of gradient vector is perpendicular to the direction of an edge at (x, y).

-1	-1	-1
0	0	0
-1	-1	-1

-1	0	-1
-1	0	-1
-1	0	-1

Fig.4 Masks used for Prewitt Edge operator

B. Second-Order Derivative

It is positive at the darker side and negative at the white side. It is very sensitive to the noise present in an image, that's why it is not used for edge detection. But, it is very useful for extracting some secondary information i.e. we can find out whether the point lies on the darker side or the white side.

Zero-crossing: It is useful to identify the exact location of the edge where there is gradual transition of intensity from dark to bright region and vice-versa. Reference [3] described a digital step edge operator which detects edges at all pixels whose estimated second directional derivative taken in the direction of the gradient has a zero crossing within the pixel's area. There are several second-order derivative operators:

1. Laplacian of Gaussian (LoG) operator

As Laplace operator may detect edges as well as noise (isolated, out-of-range), it may be desirable to smooth the image first by convolution with a Gaussian kernel of width σ

$$G_\sigma(x,y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (13)$$

to suppress the noise before using Laplace for edge detection

$$\Delta[G_\sigma(x,y) * f(x,y)] = [\Delta G_\sigma(x,y)] * f(x,y) = LoG * f(x,y)$$

$$\frac{d}{dt}[h(t) * f(t)] = \frac{d}{dt}\int f(\tau)\, h(t-\tau)\, d = \int f(\tau) \frac{d}{dt} h(t-\tau)\, d\tau = f(t) * \frac{d}{dt} h(t) \quad (14)$$

We can obtain the Laplacian of Gaussian $\Delta G_\sigma(x,y)$ first and then convolve it with the input image. To do so, first consider

$$\frac{\partial}{\partial x} G_\sigma(x,y) = \frac{\partial}{\partial x} e^{-\frac{x^2+y^2}{2\sigma^2}} = -\frac{x}{\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (15)$$

and

$$\frac{\partial^2}{\partial x^2} G_\sigma(x,y) = \frac{x^2}{\sigma^4} e^{-\frac{x^2+y^2}{2\sigma^2}} - \frac{1}{\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \frac{x^2-\sigma^2}{\sigma^4} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (16)$$

For simplicity, we omit the normalizing co-efficient $\frac{1}{\sqrt{2\pi\sigma^2}}$. Similarly, we can also get,

$$\frac{\partial^2}{\partial x^2} G_\sigma(x,y) = \frac{y^2-\sigma^2}{\sigma^4} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (17)$$

The LoG operator or convolution kernel is defined as

$$LoG \triangleq \Delta G_\sigma(x,y) = \frac{\partial^2}{\partial x^2} G_\sigma(x,y) + \frac{\partial^2}{\partial y^2} G_\sigma(x,y) = \frac{x^2+y^2-2\sigma^2}{\sigma^4} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (18)$$

This 2D LoG can be approximated by a 5-by-5 convolution kernel such as Fig. 5.

0	0	1	0	0
0	1	2	1	0
1	2	-16	2	1
0	1	2	1	0
0	0	1	0	0

Fig. 5 Masks used for LoG operator

Fig. 5 shows a 5×5 mask that approximates $\Delta G_\sigma(x,y)$. This approximate is not unique. Its purpose is to capture the essential shape of $\Delta G_\sigma(x,y)$ i.e. a positive central term, surrounding by an adjacent negative region that increases in value as a function of distance from the origin and a zero outer region. The coefficients also must sum to zero so that the response of the mask is zero in areas of constant gray level. The purpose of the Gaussian function in the LoG formulation is the smooth the image and the purpose of the Laplacian operator is to provide an image with zero crossing to establish the location of edges.

C. Canny Operator

It is used to find edges by isolating noise from the image before find edges of images, without affecting the features of the edges in the image and then applying the tendency to find the edges in the image and the critical value for threshold [4].

1. *Convolve image f(r, c) with a Gaussian function to get smooth image $\hat{f}$(r, c).*

$$\hat{f}(r, c) = f(r, c) * G(r, c) \quad (19)$$

2. *Apply first difference gradient operator to compute edge strength.*
3. *Apply non-maximal or critical suppression to the gradient magnitude.*
4. *Apply threshold to the non-maximal suppression image.*

III. Experimental Results and Discussions

Thresholds are defined independent of the algorithm. Thresholds provide a way to measure differences in performance over large ranges. For example, is one algorithm worse than another by a 10% difference in the threshold, a 100% difference, or a 1000% difference? Thresholds give a way of distinguishing between large and small effects [6]. The authors have been taken the threshold parameter to analyze the various edge operators. They have been chosen the different images to measure the effectiveness of various edge operators. The Prewitt, Sobel, LoG and Canny operator have taken for experiments. Table I shows the results.

TABLE I
Comparison of Various Edge Operators of Different Images Using Threshold Parameter

Parameters / *Image*	*Prewitt*	*Sobel*	*LoG*	*Canny*
University	0.1740	0.1762	0.0078	0.0625, 0.1563
Building	0.1294	0.1308	0.0062	0.0625, 0.1563
Child	0.0445	0.0451	0.0020	0.0438, 0.1094
Moon	0.0786	0.0801	0.0024	0.0188, 0.0469

The graph has been shown in Fig. 6.

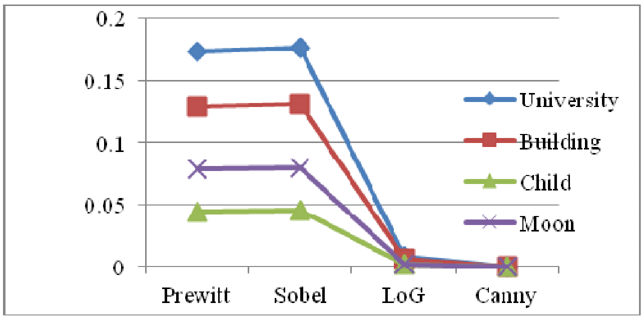

Fig. 6 Comparison of the various Edge operators

The various edge detectors have been implemented in MATLAB using Image Processing Toolbox (IPT) and the results have been shown in Fig. 7.

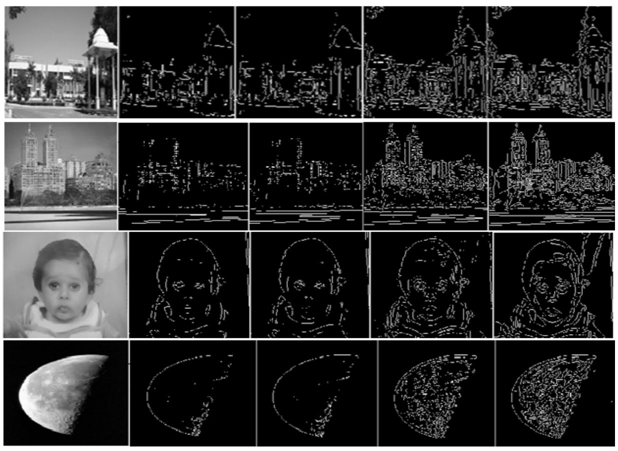

Fig. 7 (a) Original Image, (b) Prewitt, (c) Sobel, (d) LoG, and (e) Canny

These different operators respond to changes in gray level or average gray level. For Prewitt operator, the response to the diagonal edge is weak, while for Sobel operator it is not that weak as it gives greater weights to points lying close to the point (x, y) under consideration. However, both Prewitt and Sobel operator's posses greater noise immunity. These operators also called the first difference operator. Laplacian of Gaussian (LoG), on the other hand, is a second difference operator. A good edge detector should be a filter with the following two features: (1) It should be a differential operator, taking either a first or second spatial derivative of the image. (2) It should be capable of being tuned to act at any desired scale, so that large filters can be used to detect sharply focused fine details. According to N. R. Pal [5], the most satisfactory operator fulfilling these conditions is the Laplacian of Gaussian (LoG) operator. The Gaussian part of the LoG operator blurs the image, wiping out all structures at scales much smaller than the σ of the Gaussian. The Gaussian blurring function is preferred over others because it has the desirable property of being smooth and localized in both spatial and frequency domains. According to Canny [4], a good edge detector should have the following three properties: (1) low probability of wrongly marking non-edge points and low probability of failing to mark real edge points (i.e. good detection); (2) points marked as edges should be as close as possible to the centre of true edges (i.e. good localization); and (3) one and only one response to a single edge points (single response). Good detection can be achieved by maximizing signal-to-noise ratio (SNR), while for good localization; Canny used the reciprocal of an estimate of the root mean square distance of the marked edge from the center of the true edge. To maximize simultaneously both good detection and localization criteria, he has maximized the product of SNR and the reciprocal of standard deviation (approximate) of the displacement of edge points. The maximization of the product is done subject to a constraint which eliminates multiple responses to a single edge points.

IV. Conclusion

In this paper, authors have been analyzing various image segmentation techniques which highlight the edge-based approach. In edge detection method, authors have been analyzed various operators such as Prewitt, Sobel, LoG and Canny. These different edge operators have been implemented in MATLAB using Image Processing Toolbox (IPT). The Prewitt operator gives the weak response to the diagonal edge while Sobel operator gives the strong response. However, both of these operators posses greater noise immunity. In LoG, intensity changes occur at different scales in an image. Sobel is 1.26% better than Prewitt operator. Canny is 10.17, 11.29% and 70.12% better than Prewitt, Sobel and LoG operator respectively. In short, the Canny edge detector gives the better results as compare to other edge detectors because it provides good detection, good localization and single response.

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Rajiv Kumar obtained M. Tech (CSE) from Guru Jambeshwar University, Hissar, Haryana in 2005. He is pursuing Ph.D. from Bharathiar University, Coimbatore, Tamil Nadu. During 2005-2009, he served as Lecturer in R V College of Engineering, Bangalore. Currently, he is working as Assistant Professor in Gurgaon Institute of Technology and Management, Gurgaon, Haryana. He has published 13 papers in National/International Conference and 2 papers are in International Journal. He has participated in various programme/workshop/conference from different organization like Infosys, Wipro, RVCE etc. He is member of CSI. His area of interest is image processing, computer vision and pattern recognition.

Dr. Arthanariee A. M holds a Ph.D. in Mathematics from Madras University as well as Masters Degree in Computer Science from BITS, Pilani. He holds patent issued by the Govt. of India for the invention in the field of Computer Science. He has directed teams of Ph.D researchers and industry experts for developing patentable products. He teaches strategy, project management, creative problem solving, innovation and integrated new product development for last 35 years.