Analysis of Edge Detection Methods in Image Processing

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---**ABSTRACT**---
Image processing is a very effective method for interpreting the contents of an image and process them for various uses. The main objective of image processing is to find the meaningful and valid information from the contents of the image. Digital image processing has achieved a lot of attention from the researchers in this era. The interpretation of digital images through the various image processing techniques and algorithms has helped a lot of researchers for analysing images to collect valuable information in various fields. The image processing algorithms allows us to use simple and effective algorithms which will give lots of information which is not possible by other analog means. Image segmentation is a method in which we divide the images into smaller regions of similar contrast, is an essential process in the handling of a digital images. It allows us to read the image more efficiently and analyse each part more carefully. The best technique for image segmentation is edge detection. Detecting the edges which reside in the image helps for segmenting an image properly. Edge can be termed as fundamental feature present in an image. A digital image is a set of pixels to represent each point in the image which display a certain contrast or shade. An image contains different regions with different contrast. The edge detection process detects such variations in contrast. This process allows us to filter image by removing unnecessary information but keeping significant information. Edge detection greatly reduces the size of the image while preserving its features and structure. The edge detection method identifies different patterns in images and give proper size and shape of different objects and structures in an image. In this paper, we will discuss standard edge detection algorithms which are used for image processing. We will be discussing about the role of Robert, Prewitt andSobel operator, Canny operator andLaplacian of Gaussian detector etc.
Keywords: **Image segmentation, Edge detection, Robert operator, Laplacian of Gaussian detector,Prewitt operator, Canny operator, Sobel operator.**

I. Introduction

The method of analysing and interpreting the digital images with the help of mathematical operators and algorithms using a computer is known as image processing. An image contains various information like the structure of the objects, shade, colour, contrast, size, orientation, texture etc. For image processing, we give an image as an input and the outcome can be or not exactly an image but a set of pixels which defines the structure and features of the image or shape features of the image. This can be very useful for researchers who works on materialistic operations.

Image processing has a vital role in image segmentation. It segments i.e. divides the image into sub regions or areas of similarities. Each segment could refer to an object, component part or similar shade. Each individual segments can be used to carefully examine the structures and objects in the image. The segmentation is done with respect to the discontinuities and similarities within the image pixels. The pixels with similar weightage values are coupled up together and each groups are separated by the abrupt changes in the shades between them. These actions are guided by predefined criteria specified according to the requirement. The dissimilarities that separate each segment can be object orientation, materialistic properties, shades, different depths etc.

There are three basic types of dissimilarities in image. They are point, line and edge. These discontinuities are used to segment the images into different region. Edge detection is used to find the dissimilarities between pixels.Edge is a dividing line between two sectors with comparatively distinguishable gray level properties that separate sectors in an image. It identifies the changes in the shades, colour, scene, pattern to identify regions for segmentation. The edge detector identifies various levels of grey, or changes in the colour. We can say that the edge detector is a filter that extract the edges from the image. The main function of edge detector is to identify pixels and compare it with its neighbouring pixels to identify the change in grey level by using first order derivative or second order derivative for detecting edges. We will be discussing about various first order, second order and optimal edge detection methods.

1. Image Segmentation

Image segmentation is the process of partitioning the different regions or a group of pixels in an image. The segmentation of monochrome images is based on two kinds of values for intensity: similaritiesand discontinuity. In the approach based on discontinuity, the images are partitioned based on unanticipated changes in the intensities (like edges). The main approach is the similarity approach in which the image is segregated into segments containing pixels that are alike based on predefined criteria. All the pixels that belongs to a region has similarities based on some characteristics colour, intensity, texture etc.

We can segment an image basically by three approaches. One approach is by identifying and separating the regions based in difference in colour intensity levels. The second approach is by directly identifying the regions and edges. The next approach is by separating the regions by giving

predefined criteria to apply on pixel properties like intensity values as threshold value.

The mostly used segmentation technique region based segmentation. In region based segmentation the image is divide on the basis of continuity and similarity. The image is partitioned into sub regions where the pixels in a particular region will have the same characteristics like same shade, similar grey intensity level or pixel weightage. It can be achieved easily by providing a threshold value according to which the segmentation will be done. Until the threshold is satisfied the region will not be partitioned. This threshold value can be the intensity value of the pixels. The segmentation can be greatly influenced by the noise level of the image which can create broken segments. There is also boundary based partitioning technique which is implemented by identifying the edges to partition and separate the regions. The edges are identified by analysing the images for discontinuities based on pixel levels and intensity.

2. Edge and Edge Detection

Edges arenarrow strip between two sectors in an image which containcomparatively distinguishable gray level properties. Edges actually appear between two regions of different gray levels or discontinuities formed from difference in scene, depth, objects etc.

2.1 Types of edges

There are mainly four types of edges:

2.1.1 Step edge

A step edge occurs when there is a swift peak in the intensity values in the image sector compared to the other sector in the image, it means that there is a clear boundary between the two regions.
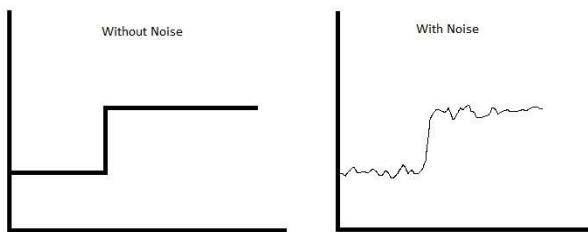
2.1.2 Ramp Edge

The ramp edge is similar to the step edge. The only difference is that in the ramp edge there is no sudden difference rather there is a gradual increase or decrease in the intensity. The change occurs over a finite distance (It increases by certain amount and takes more than one pixel to complete the change).
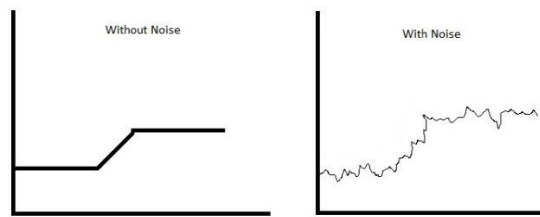
2.1.3 Line Edge

In the line edge the intensity changes abruptly first and returns back to the initial level after a short distance. This is usually caused by lines thus named as line edge.
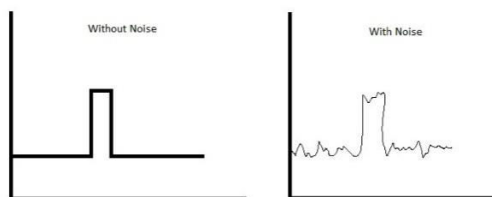
2.1.4 Roof Edge

A roof edge is similar to the line edge. The difference is that in roof edge the values of intensity changes gradually over a small distance rather than instantaneous change at a point. It is actuallycreated by the convergence of two sectors or region.
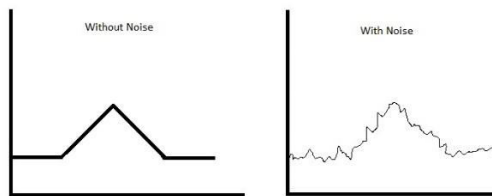
2.2 Edge Detection

The fundamental tool for image segmentation is edge detection. In this method the variation in the intensity is analysed to find the edges present in the image. The input image is converted into an edge image which contains the boundaries of different in the image thus giving the various physical and geometric properties in the scene. Edges usually occurs between different regions or objects. So the structure of the objects can be extracted by detecting its edges. It provides us with the boundaries of the objects by identifying the discontinuities in the intensity values. These edge detection mechanisms can be effectively used in medical fields.

In the edge detection method, the input image is first smoothened and refined to remove noise to a possibly maximum extent without dealing any harm to the true borders or edges in the image. Now this resultant image is enhanced to improve the quality of edges by applying the differentiation. Later we apply an edge magnitude

threshold to retain the proper edge and reject the noisy edges. At last we will use algorithms and applications to detect the edges thus resulting in the final processed image.

2.3 Different Methods for Edge Detection

There are many methods for edge detection. The main categories are the Gradient approaches and the Laplacian techniques. In the Gradient method, the edges in the image can be detected by taking its first derivative. This method can be also called as First Order Derivative. This is done by identifying the points with higher change in the grey level by applying the derivative operator. This difference can be specified by giving a threshold value. The derivative operation is implemented with the help of mask which is a set of values used to do some calculation on the pixel values. The changes in the grey values for similar shades will be small and maximum in magnitude at the position of edges.

In Laplacian method, the zero crossing point is identified by taking the second order derivative expression. Usually the image is pre-processed by applying the Gaussian smoothening technique before searching for zero crossing of nonlinear differential expression for identifying the edges.

Method	Technique(Operator)
First Order Derivatives (Gradient Method)	Robert
	Sobel
	Perwitt
Second Order Derivatives (Zero Crossing method)	Laplacian of Gaussian(LoG)
	Difference of Gaussian(DoG)
Optimal Edge Detection	Canny Edge Detector

Edge detection can be expressed as a fundamental technique for identifying the discontinuities in values of intensities even if other approaches like point detection and line detection are there. These discontinuities are calculated by taking the first order derivative values and second order derivative values. The first order derivative is calculated by taking the gradient values using a digital mask. For a function in 2-D, say f (x, y), the gradient value is expressed as a vector.

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

Where ∇f is the gradient vector for the image. The magnitude of this vector

$$\nabla f = mag(\nabla f) = \sqrt{G_x^2 + G_y^2}$$

$$= \sqrt{(\partial f/\partial x)^2 + (\partial f/\partial y)^2}$$

This value is approximated by vomiting the square root operation for easy computation as:

$$\nabla f \approx G_x^2 + G_y^2$$

Or by taking the absolute value as:

$$\nabla f \approx |G_x| + |G_y|$$

This magnitude of gradient or the approximation value can be called as 'gradient'. After the approximation, there will be zeros at the places where the intensity is constant and at places where the intensity is variable will have approximation values proportional to the degree of intensity change.

Gradient vector's main feature is that it always points to the direction which shows the maximum degree if change of function f. This angle can be calculated by the equation:

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

The second order derivative is calculated by finding the Laplacian. For a function in 2-D, namely f (x, y)

the Laplacian is formulated from the second order derivative as:

$$\nabla^2 f(x, y) = \frac{\partial^2 f(x, y)}{\partial x^2} + \frac{\partial^2 f(x, y)}{\partial y^2}$$

The Laplacian is not often used for detection of edge because a second order derivative, its magnitude can even produce double edges. It is not able to identify the direction. The Laplacian method is highly susceptible to noise. It inadvisably sensitive to noise. So it is not used alone but along with other edge detection techniques. It is used to find the edge location in the background.

There are two criteria in which the Laplacian detects the rapid change in the intensity. One is by identifying regions where the first derivative is greater than the specified threshold value. The second method is calculating the second derivative to find regions where the intensity has zero crossing.

The IPTs provide many derivative estimators to which works on the above criteria in the form of function edge. The syntax for this function which is generally used is:

[g, t] = edge (f, 'method', parameters)

Here in output,'g' is an array in which the region where the edge points are identified in function f are denoted with 1s and other regions with 0s. 't' is the threshold value specified to identify whether a gradient value can be categorized as an edge point. 'f' is the image to be processed. 'method' is the type of technique according to which the edge is detected. 'parameters' are additional information provided to the edge function.

C1	C2	C3
C4	C5	C6
C7	C8	C9

Pixel intensities

2.3.1 Robert operator

Robert operator is a gradient method which provides an easy and efficient technique to identify the edges in a digital image. The Robert operator uses a 2*2 mask to estimate the spatial gradient of an image. Each individual point in the output image refers to the measurement of spatial gradient for the corresponding point in the input. This method is effective at region having high intensity change which could correspond to an edge. The Robert operator use a pair of convolution mask which can be used to find edges in the x direction and y direction which are identical, one mask is the 90 degree rotated image of the other.

The gradient values can be calculated as;

$$G_x = f(x,y) = [f(x,y) - f(x+1, y+1)]$$

$$G_y = f(x,y) = [f(x+1, y) - f(x, y+1)]$$

Gradient magnitude is:

$$G = \sqrt{G_x^2 + G_y^2}$$

Approximation magnitude:

$$G = |G_x| + |G_y|$$

The general syntax in IPT is:

 [g, t] = edge (f, 'reberts', T, dir)

Here 'f' is input, 'T' refers to the threshold value and 'dir' refers to the direction in which the detection should be carried out. The Robert operator cannot be used to track the edges in the angles which are multiples of 45 degrees.

2.3.2 Sobel operator

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

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

The Sobel operator make use of a convolution mask in the form of 3*3 to detect all the edges that are present in an image. The Sobel operator is the resultant of two directional edge enhancement function. This method gives more importance to the central point thus giving more weightage to it. It highlights the locations which contain high spatial frequency which can match up with edges. It allows us to calculate the absolute gradient magnitude regardless of the direction. The main advantage of Sobel operator is the it can produce a smoothing effect, filter the image and supress the noise. This features allows it to produce a distinct outline of the edges in the image. The 3*3 convolution mask pair can be implemented separately to the grey scale image to create the absolute gradient magnitude for each points.

Gx   Gy

The gradient value can be calculated by:

Gx = (C7 + 2C8 + C9) – (C1 + 2C2 + C3)

Gy = (C3 + 2C6 + C9) – (C1+ 2C4 + C7)

Gradient magnitude is:

$$G = \sqrt{G_x^2 + G_y^2}$$

Approximation magnitude:

$$G = |G_x| + |G_y|$$

The general syntax in IPT is:

[g, t] = edge (f, 'sobel', T, dir)

2.3.3 Prewitt operator

Prewitt operator is a discrete differentiation operator used to calculate the magnitude and orientation present in an image. The Prewitt operator is in a way resembles to the Sobel operator but the difference is that the Prewitt operator do not give emphasis on the central point. The Prewitt operator is much easier to implement and compute but is susceptible to noise. It can identify edges in eight directions but all of them are not accurate or perfect. It sometimes produces noisy outputs due to its vulnerability to noisy images.

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

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

GxGy

The gradient value can be calculated by:

Gx = (C7 + C8 + C9) – (C1 + C2 + C3)

Gy = (C3 + C6 + C9) – (C1 + C4 + C7)

Gradient magnitude is:

$$G = \sqrt{G_x^2 + G_y^2}$$

Approximation magnitude:

$$G = |G_x| + |G_y|$$

The general syntax in IPT is:

 [g, t] = edge (f, 'prewitt', T, dir)

2.3.4 Laplacian of Gaussian Detector(LoG)

This method uses a second derivative approach. The Laplacian operation on a function or second order derivative of a function is defined as:

$$\nabla^2 f(x,y) = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

The Laplacian of Gaussian detector works in two steps. The first step is to use some operations to smoothen and filter the noise in the image like the Gaussian smoothing filter and calculates the Laplacian. This results in the formation of double edge image. Then this image is used to identify the zero crossing points of the double edges, which will eliminate the unwanted points or regions.

0	1	0
1	-4	1
0	1	0

1	1	1
1	-8	1
1	1	1

-1	2	-1
2	4	2
-1	2	-1

The LoG function on zero crossing and standard Gaussian deviation is:

$$LoG(x,y) = -\frac{1}{\pi\sigma^4}\left[1 - \frac{x^2 + y^2}{2\sigma^2}\right]e^{\frac{x^2+y^2}{2\sigma^2}}$$

The general syntax in IPT is:

[g, t] = edge (f, 'log', T, sigma)

Here 'sigma' indicate the standard deviation with a value defaulted to 2. Also if the value of 'T' is not specified, it will be automatically assigned.

2.3.5 Difference of Gaussian Detector(DoG)

DoG uses second order derivative approach. This method is similar to LoG edge detector. It first smoothens the image by using a convolution mask, i.e. a Gaussian blur, with a standard deviation σ_1. On the resultant blurred image, we again preform blur operation with another sharper standard deviation σ_2. The final image is then obtained by finding the difference between the two blurred. This final image is used to detect the edges. The Difference of Gaussian is a band-pass filter which eliminates the noise which is represented as high frequency components and some same intensity regions represented as low frequency components. This resultant image is checked for zero crossing which refers to edges or locations with some discontinuities. The edges in the image can be detected by the following steps:

- Apply the DoG operation by using two standard deviation value and find the difference.
- Identify the zero crossing in the resultant image to detect the discontinuities.
- Apply a thresh hold value to select those values with strong variations and neglect the others. This step is useful in removing the discrete zero crossing formed by the noise.

The general formula of DoG operator is:

$$G_{\sigma 1}(x,y) = \frac{1}{\sqrt{2\pi\sigma_1^2}}\exp\left(-\frac{x^2 + y^2}{2\sigma_1^2}\right)$$

First Gaussian blur is:

$$g1(x,y) = G_{\sigma 1}(x,y) * f(x,y)$$

Second Gaussian blur is:

$$g2(x,y) = G_{\sigma 2}(x,y) * f(x,y)$$

Finally, the difference is:

$$DoG = G_{\sigma 1} - G_{\sigma 2}$$

$$= \frac{1}{\sqrt{2\pi}}\left(\frac{1}{\sigma 1}e^{-\frac{x^2+y^2}{2\sigma_1^2}} - \frac{1}{\sigma 2}e^{-\frac{x^2+y^2}{2\sigma_2^2}}\right)$$

2.3.6 Canny operator

Canny operator or otherwise known as optimal edge detector is one the standard edge detection methods. It produced efficient result since it separates the image from noise before extracting the edges without disturbing the features of the edges. The various steps in this edge detection method are:

- The image is smoothened by convolving it with a two dimensional Gaussian filter. If 2D Gaussian filter cannot be implemented, two 1D Gaussian filter is applied to find the x direction and y direction.
- At each points the 1st difference gradient operator is applied to obtain the strength of edge, magnitude of edge and direction of the edge.
- The resultant edge points in the gradient magnitude image creates ridges. These ridges are then tracked to supress those points which are not at the ridge top. These points can also be supressed by taking each points in the gradient image and comparing this points with all points which are at one-pixel distance either in positive or negative direction. If the gradient value is not greater, then the point is suppressed.
- The last step is thresholding. In this step, the pixel value is compared with the high and low threshold values. If the pixel value is greater than the higher threshold value or the pixel weightage value is higher than the low threshold value as well as neighbour to an edge pixel, it is marked as edge pixel. Else it is not marked as edge pixel.

The general syntax in IPT is:

[g, t] = edge (f, 'log', T, sigma)

Here 'T' indicates to high and low threshold. T = [T1, T2], and is automatically calculated if not specified. The threshold 't' in the resultant set of argument, it is a vector which consist of two threshold values. The default value of sigma is 1.

II. Conclusion

Image processing is a widely used field in this era of computer vision. The advancement in the digital imaging, artificial intelligence and computer processing has fuelled its growth. An attempt is done in this paper to discuss the basic edge detection techniques. There are many more edge detection techniques developed. This paper is reduced to the basic edge detection techniques. The tests were carried out in MATLAB software. Form the experiment the Canny operator has provided the best output compared to other techniques. The noise in the image plays a drastic role which very much influences the output. Anyway all the techniques are good in their own way. The output of each algorithm differs on the condition and environment they are put into. Each algorithm works perfectly if applied on the environment for which it was developed. The image processing is a growing field and I hope that this paper would help the researchers who are new to this field to understand these basic techniques.