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Study and Analysis of Edge Detection Techniques in Digital Images

Shiva Sharma*[1], Vandana Mahajan[2]
*[1,2]Department of Electronics and Communication Engineering, Vaishno College of Engineering, Thapkour, Nurpur, Kangra, Himachal Pradesh, India

ABSTRACT

This work provides a review of various techniques which have been presented in literature for detection of edges in digital images. Various techniques have been proposed over the years using linear and nonlinear gradient operators. Apart from these operators, techniques such as fuzzy logic have also been used for edge extraction. These detection techniques have also been used for various applications such as image restoration, segmentation, object detection and so on.

Keywords: Edge Detection, Operator based edge extraction, Canny, Sobel, Prewitt, Fuzzy Logic

I. INTRODUCTION

The use of image processing helps to improve the image quality and analysis for different applications. This field has a broad spectrum of application such as remote sensing via satellite and other spacecrafts, image transmission and storage, medical, radar, sonar and acoustic image processing, robotics and automated inspection of industrial products. As an important image processing technique, edge detection plays a key role in practical applications such as medical science, remote sensing, satellite imaging and so on.

When it comes to digital images, edge is a feature can be considered as a discontinuity in light intensity of pixels in an image and represent high frequency data. Edge is considered an important feature in a digital image and is used for image enhancement, restoration and segmentation.

Edge detection is a fundamental tool in image processing and computer vision, particularly in the areas of feature detection and feature extraction, which aim at identifying points in a digital image at which the image brightness changes sharply or more formally has discontinuities. The contrast is improved by increasing the difference across discontinuities of the image components. In order to improve the differences, they have to be detected. The edge detection algorithm is designed to detect and highlight these discontinuities. Discontinuities in image brightness are likely to correspond to discontinuities in depth, discontinuities in surface orientation, changes in material properties or variations in scene illumination. The purpose of detecting sharp changes in image brightness is to capture important events and changes.

The goal of edge detection is to locate the pixels in the image that correspond to the edges of the objects seen in the image. This is usually done with a first and/or second derivative measurement following by a comparison with threshold which marks the pixel as either belonging to an edge or not. In the ideal case, the result of applying an edge detector to an image may lead to a set of connected curves that indicate the boundaries of objects, the boundaries of surface markings as well as curves that correspond to discontinuities in surface orientation. Thus, applying an edge detection algorithm to an image may significantly reduce the amount of data to be processed and may therefore filter out information that may be regarded as less relevant, while preserving the important structural properties of an image.

Figure 1. Example of an image with its edges

II. Edge Detection

Various edge detection algorithms have been developed in the process of finding the perfect edge detector. Most of conventional operator based techniques may be grouped into two types:

1) Gradient (difference) based operators: In the gradient based edge detection we find an estimate of the gradient magnitude using the smoothing filter and use the found estimate to determine the position of the edges. It means that the gradient method detects the edges by looking for the maximum and the minimum in the first derivative of the image. Magnitude of the gradient of image is given by

$$\left|grad\ f\left(x,y\right)\right| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \qquad (1)$$

It is based on the investigation of the image function's behaviour in a small neighbourhood. The practical implementation is done via convolution masks. The operators approximating first derivatives have to contain separate masks for each direction. But in vast majority of cases, only the differences in the vertical and horizontal directions are calculated which means that only two convolution masks are used. These operators are, for example, Canny Operator, Roberts operator, Prewitt operator, Sobel operator etc. All the kernels are mostly normalized.

2) Laplacian (zero-crossing) based operators: In the Laplacian method we find the second derivative of the signal and the derivative magnitude is maximum when second derivative is zero. In short, Laplacian method searches for zero crossings in the second derivative of the image to find edges. The original image can be easily restored from its edges.

$$\left|lap\ f\left(x,y\right)\right| = \nabla^2 f\left(x,y\right) = \frac{\partial^2 f\left(x,y\right)}{\partial x^2} + \frac{\partial^2 f\left(x,y\right)}{\partial y^2} \qquad (2)$$

The Laplacian operator has the ability to detect the edges by convolution with a single mask. It comes from the fact that if the edge is the extreme of first derivative, the second derivative should be zero.

3) Operators based on Parametric edge: These try to estimate continuous image function from the discrete image. This is, of course, very complicated and computationally demanding. Nevertheless, their results seem to be more reliable than the results of classical convolution mask methods and could work on the sub-pixel level.

Several algorithms exist for edge detection. A good edge detection algorithm should satisfy all of the below conditions:

1) Good detection: There should be maximum number of good edges.
2) Noise sensitivity: Edge detection algorithms should be able to detect edges with acceptable noise.
3) Good localization: The edge location must be reported as close as possible to the correct position, i.e. edge localization accuracy (ELA).
4) Orientation sensitivity: The operator not only detects edge magnitude, but it also detects edge orientation correctly.
5) Speed and efficiency: The algorithm should be fast enough to be usable in animate processing system. An algorithm that allows recursive implementation or separately processing can greatly improve efficiency.

III. Literature Review

Over the years, many researchers have proposed various types of edge detection algorithms [5]. Initially, a lot of work was done to present linear and non-linear operators. In recent years, many researchers have supported objectives of optimization of edge detection. Traditional methods such as Roberts [1], Sobel [2] and Prewitt [3] do not carry out edge correction optimally and also are very sensitive to noise. Canny [4] technique improved edge detection but still it suffered from some drawbacks. Thus, new methods have been developed by researchers all over the world.

One of the early work in the field of edge detection in digital images include Rosenfeld's work on non linear operator [6]. In his work, major edges in a picture were detected by subtracting averages taken over pairs of adjacent non-overlapping neighborhoods, but this method does not locate the edges precisely. He found that using a product of such differences of averages tends to yield sharply localized edges.

Griffith [7] proposed a system of programs for the detection of the straight edge lines in simple scenes. Distinct lines were detected by a procedure which was relatively inexpensive. Then, the more subtle lines are located by a search that is much more costly per unit area, but which is only applied to certain areas suggested by the locations of the lines already found.

Sun et. al. [8] proposed a nonlinear point operator, followed by a usual edge detector, e.g. the Sobel edge detector. Three point operator functions were defined and their effects on edge detection were analysed.

Stanger [9] presented a new technique for combining restored images which have different characteristics. Images were combined at the pixel level by performing a weighted average operation where the weights are derived from local image gradients estimated by the Sobel edge detector.

Gradient edge operators such as the Sobel, Prewitt and Roberts operators all required a square root operation which is computationally intensive. Mitchell [10] proposed a new square root algorithm specifically designed for use with these edge operators.

Gongyuan et. al. [11] proposed a modified morphological gradient which can overcome the drawbacks of the basic gradient approach for edge detection; provision of only a magnitude response without edge orientation, magnitude response which is dependent on the orientation of the object edge and more sensitivity to added noise than well known linear gradient estimators.

Da-Shun et. al. [12] presented a method of edge parameters extraction based on the vertical template in the Sobel operator combining the inter-frames correlation of the target and background in image series. This method decreased the superfluous pixels of background and increase the processing speed of edge detection.

Boonchieng et. al. [13] proposed an edge detection and segmentation method for two-dimensional echocardiogram to present the procedures to detect and segment an image from two-dimensional echocardiogram and to generate a scanline that can be used to detect the distance between two endocardiums which is useful to analyze heart disease.

Liang et. al. [14] presented a new edge detection method. The main contribution was the application of empirical mode decomposition (EMD) to detect the image edge. The EMD algorithm can decompose any nonlinear and non-stationary data.

Zhongshui et. al. [15] proposed color image edge detection method based on conversion transformation between RGB color space and YUV color space and histogram equalization transformation.

Zhang et. al. [16] presented a key technique based on image edge detection algorithm which adopts the Canny operator to accomplish the job of edge detection and foreground object extraction from the perspective of image processing, also has been compared with other detection methods. Chaple et. al. [17] presented a paper for real-time image processing applications on reconfigurable device like FPGAs.

Recently, Yuan et. al. [18] presented an adaptive image edge detection algorithm based on Canny operator. Method combines global with local edge detection to extract edge. The global edge detection can obtain the whole edge, which uses adaptive smooth filter algorithm based on Canny operator.

IV. Techniques

This section describes various techniques and operators which have been used for edge detection in digital images. For simulation of each of the technique, image shown in Fig. 2 is used. The results of edge extraction are shown in each case.

A. *Roberts Cross Edge Detector*

The Roberts Cross operator performs a simple, quick to compute, 2-D spatial gradient measurement on an image. It thus highlights regions of high spatial frequency which often correspond to edges. In its most common usage, the input to the operator is a grayscale image, as is the output.

Figure 2. Image used for simulation

Pixel values at each point in the output represent the estimated absolute magnitude of the spatial gradient of the input image at that point. The convolution masks of the Roberts detector are given below:

1	0
0	-1

0	1
-1	0

Figure 3. Roberts Cross Edge Detector

The result of the application of Roberts edge detector is shown in Fig. 4.

(a)

(b)

(c)

Figure 4. Roberts Cross Edge Detector Results. (a) Application of first kernel (b) Application of Second kernel (c) Combined image magnitude

B. *Sobel Operators*

Sobel Operators are the computation of the partial derivation in gradient may be approximated in digital images. This technique performs 2D spatial gradient measurement on an image and also it emphasizes regions of high spatial frequency that correspond to edges. Typically it is used to find the approximate absolute gradient magnitude at each point in an input grayscale image.

In theory at least, the operator consists of a pair of 3 × 3 convolution masks as shown in figure. One mask is simply the other rotated by 90º. These masks can be separate measurements of the gradient component in each orientation that is Gx and Gy. These can be combined together to find the absolute magnitude of the gradient at each point and the orientation of that gradient. The convolution masks of the Sobel detector are given in Fig. 5.

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

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

Figure 5. Sobel Edge Detector

The result of the application of Sobel edge detector is shown in Fig. 6.

C. *Prewitt Operator*

The prewitt operator is an approximate way to estimate the magnitude and orientation of the edge. The prewitt operator uses the same equations as the Sobel operator, except the central coefficient of 1 instead of 2. This prewitt operator does not place any emphasis on pixels that are closer to the centre of the masks.

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

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

Figure 6. Prewitt Edge Detector

This operator will measure two components. The vertical edge component is calculated with kernel Gx and the horizontal edge component is calculated with kernel Gy. |Gx| + |Gy| give an indication of the intensity of the gradient in the current pixel. The convolution masks of the Prewitt detector are shown in Fig. 7. The result of the application of Prewitt edge detector is shown in Fig. 8.

D. *Scharr Operators*

Scharr operators result from an optimization minimizing weighted mean squared angular error in Fourier domain. This optimization is done under the condition that resulting filters are numerically consistent. In is an improvement over Sobel operator.

The result of the application of Scharr edge detector is shown in Fig. 10.

(a)

(b)

(c)

Figure 7. Sobel Edge Detector Results.
(a) Application of first kernel (b) Application of Second kernel (c) Combined image magnitude

(a)

(b)

(c)

Figure 8. Prewitt Edge Detector Results.
(a) Application of first kernel (b) Application of Second kernel (c) Combined image magnitude

-3	0	3
-10	0	10
-3	0	3

3	10	3
0	0	0
-3	-10	-3

Figure 9. Scharr Edge Detector

E. *Canny Operator*

Canny finds edges by looking for local maxima of the gradient of f(x,y). The gradient is calculated using the derivative of a Gaussian filter. The method uses two thresholds to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges. Therefore, this method is more likely to detect true weak edges. The implemented Canny edge detector presented the best performance. Both visually and quantitatively based on the measures such as mean square distance, error edge map and signal to noise ratio. Using the implemented canny edge detector as an enhancement tool for remote sensing images, the result was robust and achieved a very high enhancement level.

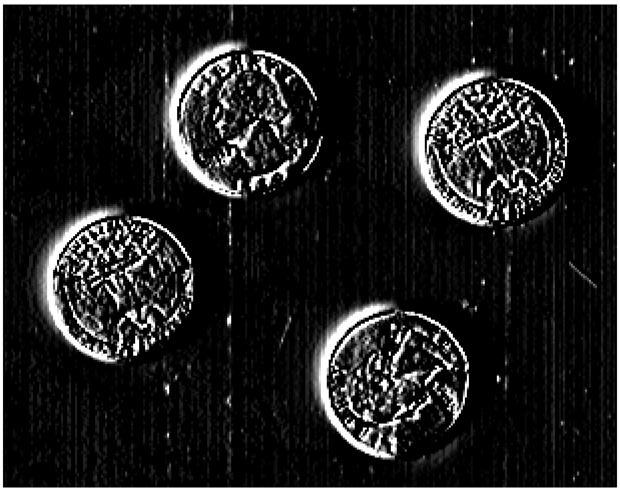
F. *Fuzzy Logic Based Edge Detector*

Fuzzy logic [19] is a perfect problem-solving methodology with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. It means that fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Fuzzy logic and probability theory are the most powerful tools to overcome the imperfection.

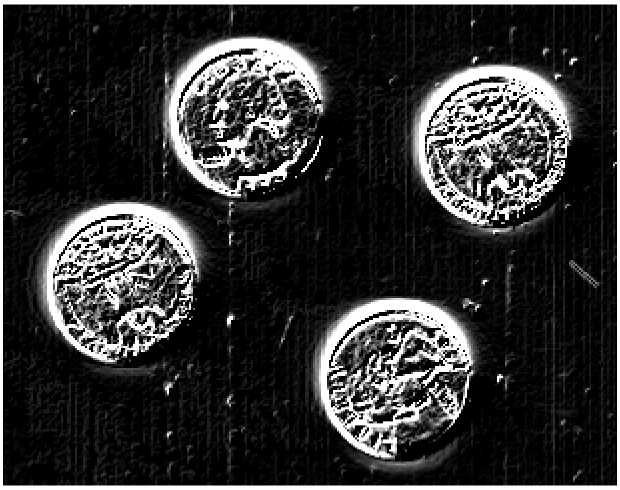
Fuzzy logic, is a version of first-order logic which allows the truth of a statement to be represented as a value between 0 and 1, rather than simply True (1) or False (0).

To perform image processing using fuzzy logic, three stages must occur. First, image fuzzification is used to modify the membership values of a specific data set or image. The image(s) used is(are) the gradient images obtained from the original images. After the image data are transformed from gray-level plane to the membership plane using fuzzification, appropriate fuzzy techniques modify the membership values. The image data is transformed based on these inference rules. This can be a fuzzy clustering, a fuzzy rule-based approach, or a fuzzy integration approach. Decoding of the results, called defuzzification, then results in an output image. An example of fuzzy based edge detection is shown in Fig. 11.

(a)



(b)



(c)

Figure 20. Scharr Edge Detector Results. (a) Application of first kernel (b) Application of Second kernel (c) Combined image magnitude

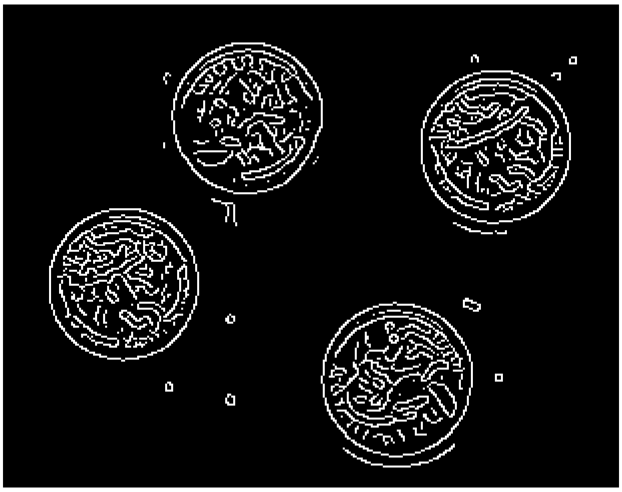


Figure 31. Canny Edge Detector Results.

Figure 42. Fuzzy logic based Edge Detector Results

V. CONCLUSION

In this paper, various concepts related to edge detection in digital images are studied. A brief literature review of initial and recent work in this field is included. Several operators used for edge detection are discussed and their working along with results is presented. Apart from the conventional operators, a newer technique for edge detection based on fuzzy logic is introduced, explained and simulation results are presented.

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