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A Comparative Assessment of the Performances of Different Edge Detection Operator using Harris Corner Detection Method

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ABSTRACT

Edge detection is one of the most commonly used and one of the most important operations in image processing which reduces the useless information while retaining the important structural properties of an image. Here a comparative study of Sobel, Roberts, Prewitt, LoG, Canny, Zerocross algorithms are conducted and corner points using Harris Corner detection algorithm on the image are obtained after applying edge detection operators.

General Terms

Algorithm, Operator, Edge detection, Corner point detection.

Keywords

Sobel, Roberts, Prewitt, LoG, Canny, Zerocross, Harris Corner.

1. INTRODUCTION

An edge is the boundary between an object and the background, and indicates the boundary between overlapping objects. Edge detection is the process of identifying discontinuities in images.

Several variables are involved in selection of an edge detection operator such as edge orientation, noise environment, and edge structure. The geometry of the operator determines the characteristic direction in which it is most sensitive to edges. Edge detection is difficult in noisy images since both the noise and edges contain high frequency content[1]. Reduction of noise results in blurring and distortion of image, removal of which results in less accurate localization of edges. Effects such as refraction or poor focus results in objects with boundaries defined by gradual change in intensity. Thus edge detection operators chosen must be responsive to such changes. Therefore problems of edge detection are false edge detection, missing of true edges, edge localization etc. Thus, here various edge detection techniques are compared and corner points on the edge detected images are generated using Harris Corner Detection algorithm. Here the very popular image of Lena has been taken for our research purpose.

Figure 1. Lena (Original Image)

2. EDGE DETECTION OPERATORS

2.1 Sobel Operator

Mathematically, Sobel Operator uses two 3×3 matrix which are convolved with the original image to calculate approximations of the derivatives - one for horizontal changes, and one for vertical changes. The horizontal and vertical derivative approximations are given as follows:

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

G_x

1	2	1
0	0	0
1	2	1

G_y

Figure 2. Masks used by Sobel Operator

The *x*-coordinate is defined as increasing in the right-direction, and the *y*-coordinate is defined as increasing in the down-direction.The resulting gradient approximations can be combined to give the gradient magnitude, using:

$$G=(G_x^2+G_y^2)^{1/2}$$

Using the above equation, the gradient's direction can also be calculated:

$$\Theta = \operatorname{atan}\left(\frac{\mathbf{G}_y}{\mathbf{G}_x}\right)$$

where, for example, Θ is 0 for a vertical edge which is darker on the right side.

Figure 3.a) Lena after applying Sobel

Visual Inference : In the above image(Figure 3.a) it can be seen that Sobel detects the edges of the image but breaks the continuity of the edges which leads to lack of prominence . As a result, the image cannot be visually identified properly. Now Harris Corner Detection algorithm is applied on this image (Figure: 3.a) to generate the corner points. As a result, 14 corner points are generated which are shown in Figure:3.b.

Figure 3.b) Harris corner implemented on Sobel edge detected image (Fig 3.a)

Table 1. Table representing Harris-Corner points for Sobel edge detected image

Operators	X-Coordinate	Y-Coordinate
SOBEL	32	85
	167	138
	161	152
	204	158
	222	162
	247	171
	186	175
	120	228
	224	139
	194	240
	32	296
	275	296
	33	339
	222	339

2.2 Robert's Cross Operator:

An edge detector should have the following properties: the edges produced should be well-defined, the background should have little noise, and the intensity of edges should be close to human perception. With these criteria, Roberts proposed the following equation

$$y_{i,j} = \sqrt{x_{i,j}}$$
$$z_{i,j} = \sqrt{(y_{i,j} - y_{i+1,j+1})^2 + (y_{i+1,j} - y_{i,j+1})^2}$$

where x is the initial intensity value in the image, z is the computed derivative and i, j represent the location in the image. The results of this operation highlights changes in intensity in a diagonal direction.

In order to perform edge detection with the Roberts operator, first the original image is convolved, with the following two kernels:

$$\begin{bmatrix} +1 & 0 \\ 0 & -1 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} 0 & +1 \\ -1 & 0 \end{bmatrix}.$$

Figure 4 . Mask for Robert's cross Operator

Let I(x,y) be a point in the original image and $G_x(x,y)$be a point in an image formed by convolving with the first kernel and $G_y(x,y)$ be a point in an image formed by convolving with the second kernel. The gradient can then be defined as:

$$\nabla I(x,y) = G(x,y) = \sqrt{G_x^2 + G_y^2}.$$

The direction of the gradient can also be defined as follows:

$$\Theta(x,y) = \arctan\left(\frac{G_y(x,y)}{G_x(x,y)}\right).$$

Figure 5.a) Lena after applying Robert's

Visual Inference: In above image (Figure 5.a) when Robert's cross operator is implemented, it is seen that it detects the edges but not as minutely as Zerocross, Canny and Sobel. As a result, most of the detailing of the image is lost making it even less recognizable than other detectors. When Harris Corner Detection algorithm is applied on image (Figure 5.a), 14 corner points are generated (Figure 5.b).

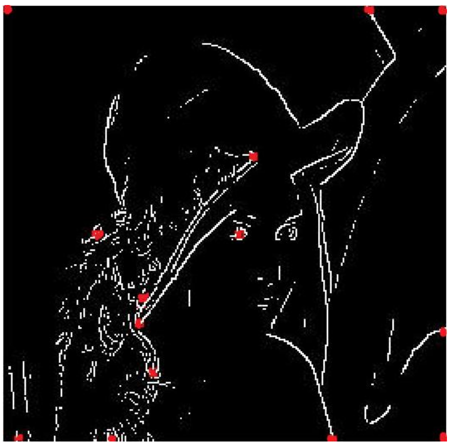


Figure 5.b) Harris corner implemented on Robert's edge detected image (Fig 5.a)

Table 2. Table representing Harris-Corner points for Robert's edge detected image

Operators	X-Coordinate	Y-Coordinate
ROBERT'S	32	85
	286	92
	165	137
	286	146
	217	162
	206	163
	246	170
	165	220
	119	228
	286	274
	32	296
	33	339
	222	339
	286	339

2.3 Prewitt's Operator

Prewitt's Operator is similar to Sobel Operator but detects the horizontal and vertical edges of an image. The operator uses two 3×3 matrix which are convolved with the original image to calculate approximations of the derivatives - for horizontal changes, and for vertical changes respectively. Here G_x and G_y are defined as the horizontal and vertical derivative approximations and are computed as:

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

G_x

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

G_y

Figure 6. Mask for Prewitt Edge detector

Figure 7.a) Lena after applying Prewitt's

Visual Inference: In edge detection using Prewitt's operator, it is observed that Prewitt detects edges (Figure: 7.a) better than Sobel and Robert's but is not as detailed as Canny, LoG and Zerocross. When Harris Corner Detection algorithm is applied on Figure 7.a , 12 corner points are generated (Figure:7.b).

Figure 7.b) Harris corner implemented on Prewitt's edge detected image (Fig 7.a)

Table 3. Table representing Harris-Corner points for Prewitt's edge detected image

Operators	X-Coordinate	Y-Coordinate
PREWITT'S	32	85
	286	92
	286	99
	286	114
	167	138
	286	144
	224	239
	286	275
	32	296
	33	339
	222	339
	286	339

2.4 Laplacian of Gaussian

Laplacian filters are derivative filters that are used to find areas of edges in images.Derivative filters are very sensitive to noise, it is common to smooth the image using a Gaussian filter before applying the Laplacian. This two-step process is called the Laplacian of Gaussian (LoG) operation.

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

A possible matrix that approximates the effect of the Laplacian is

$$\begin{pmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

This is called a negative Laplacian because the central peak is negative. It is just as appropriate to reverse the signs of the elements, using -1s and a +4, to get a positive Laplacian. To include a smoothing Gaussian filter, combine the Laplacian and Gaussian functions to obtain a single equation:

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

The LoG operator takes the second derivative of the image. Where the image is basically uniform, the LoG will give zero. Wherever a change occurs, the LoG will give a positive response on the darker side and a negative response on the lighter side. At a sharp edge between two regions, the response will be: i) zero away from the edge ,ii)positive just to one side iii) negative just to the other side iv) zero at some point in between on the edge itself.

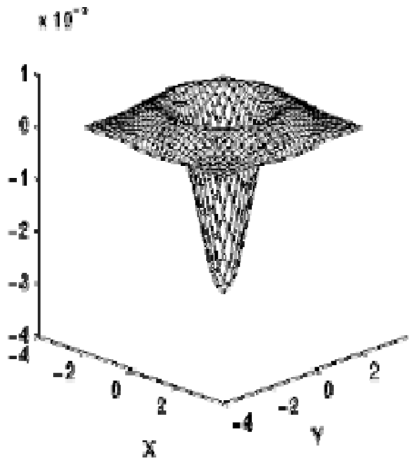


Figure 8. The 2-D LoG function.X,Y are marked in standard derivatives(σ)

Figure 9.a) Lena after applying LoG

Visual Inference: This operator detects the edges more minutely than Robert's, Prewitt's, Sobel operators respectively, but the image generated after edge detection is not as prominent as generated after using Canny operator(Figure 9.a).When Harris Corner Detection algorithm is applied on Figure 9.a, it generates 12 corner points (Figure 9.b).

Figure 9.b) Harris corner implemented on LoG edge detected image (Fig 9.a)

Table 4. Table representing Harris-Corner points for LoG edge detected image

Operators	X-Coordinate	Y-Coordinate
LoG	32	85
	286	85
	285	93
	285	104
	285	114
	285	142
	285	155
	285	162
	262	170
	251	174
	33	339
	286	339

2.5 Canny Operator

The Canny operator works in a multi-step process. Initially the image is smoothed by Gaussian convolution. In order to highlight regions of the image with high first spatial derivative, a 2-D first derivative operator is applied on the smoothed image. Edges give rise to ridges in the gradient-magnitude image. The algorithm then tracks along the top of these ridges and sets zero to all pixels that are not actually on the ridge top thus giving a thin line in the output. This process is known as non-maximal suppression. The tracking process exhibits hysteresis controlled by two threshold values: T1, T2, with T1 > T2. Tracking can only begin from a point on a ridge higher than T1. Tracking then continues in both the directions from that point until the height of the ridge falls below T2. This hysteresis ensures that noisy edges are not broken up into multiple edge fragments.

Figure 9.a) Lena after applying Canny

Visual Inference: Among all six edge detection algorithm Canny gives the best result i.e. it gives most prominent image after edge detection(Figure 9.a).When Harris Corner Detection algorithm is applied on Figure 9.a it generates 13 corner points(Figure 9.b).

Figure 9.b) Harris corner implemented on Canny edge detected image (Fig 9.a)

Table 5. Table representing Harris-Corner points for Canny edge detected image

Operators	X-Coordinate	Y-Coordinate
CANNY	32	85
	285	91
	285	103
	285	114
	251	134
	286	140
	207	146
	224	153
	130	154
	286	157
	62	167
	33	339
	286	339

2.6 Zerocross Operator

The Zerocross Operator looks for places in the Laplacian of an image where the value of the Laplacian passes through zero --- i.e. points where the Laplacian changes sign. Such points mostly occur at edges of the images --- i.e. points where the intensity of the image changes rapidly, but they also occur at places that are not as easy to associate with edges. Zero crossings always lie on closed contours, and so the output from the zero crossing detector is usually a binary image with single pixel thickness lines showing the positions of the zero crossing points.

Figure 10.a) Lena after applying Zerocross

<u>VISUAL INFERENCE</u>: Zerocross Operator gives more detailing than Sobel , Robert's , Prewitt operators respectively and less than Canny and Log operators respectively. Yet it is not as prominent and continuous as Canny (Figure 9.a).When Harris Corner Detection algorithm is applied on Figure 10.b, it generates 13 corner points (Figure 10.b).

Figure 10.b) Harris corner implemented on Zerocross edge detected image (Fig 10.a)

Table 6. Table representing Harris-Corner points for Zerocross edge detected image

Operators	X-Coordinate	Y-Coordinate
Zerocross	32	85
	234	132
	184	135
	236	142
	150	152
	210	158
	250	159
	262	170
	251	174
	146	198
	266	293
	32	295
	222	338

3. Harris Corner Detection

Harris corner detector is based on the local auto-correlation function of a signal which is used to measure the local changes of the signal with patches shifted by a small amount in different directions. Given a shift (Δx, Δy) to a point (x,y) the auto-correlation function is defined as :

$$C(x,y) = \sum w[I(x_i, y_i)-I(x_i+\Delta x,y_i+\Delta y)]^2 \quad \text{...... (1)}$$

where I (x_i, y_i) represents the image function for (x_i, y_i) points in the window W centered around (x, y). Here the Gaussian window is defined as W, where σ defines the width of the window. The shifted image is approximated by an expansion known as Taylor expansion which is truncated to first order terms as shown in equation (2):

$$I(x_i+\Delta x,y_i+\Delta y) \approx [I(x_{i,}, y_i)+[Ix(x_i, y_i)Iy(x_i,y_i)]] \; [\Delta x \; \Delta y] \quad \text{...... (2)}$$

$$c(x,y) = [\Delta x \quad \Delta y] \begin{bmatrix} \sum_W (I_x(x_i,y_i))^2 & \sum_W I_x(x_i,y_i)\, I_y(x_i,y_i) \\ \sum_W I_x(x_i,y_i)\, I_y(x_i,y_i) & \sum_W (I_y(x_i,y_i))^2 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = [\Delta x \quad \Delta y] C(x,y) \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

where Ix (x_i, y_i) and Iy (x_i, y_i) indicate the partial derivatives with respect to x_i and y_i respectively. With a filter like [-1, 0, 1] and $[-1, 0, 1]^T$, the partial derivative can be calculated from the image by substituting Eqn. (2) in Eqn. (1).

The intensity structure of the local neighborhoods is calculated by the auto-correlation matrix given by C(x, y).

Let α_1 and α_2 be Eigen values of C(x, y), there may be three cases that needs to be considered:

1. Both the Eigen values are small signifying uniform region (constant intensity).
2. Both the Eigen values are high signifying Interest point (corner)
3. One Eigen value is high signifying contour (edge)

To find out the points of interest, corner responses characterized as H(x, y) by Eigen values of C(x, y).

- C(x, y) is symmetric and positive it is definite that α_1 and α_2 are >0
- $\alpha_1 \alpha_2 = \det(C(x, y)) = AC - B^2$
- $\alpha_1 + \alpha_2 = \text{trace}(C(x, y)) = A + C$
- Harris suggested: the corner response

$\text{HcornerResponse} = \alpha_1 \alpha_2 - 0.04(\alpha_1 + \alpha_2)^2$

Finally, corner points are obtained as local maxima of the corner response.

4. Conclusion

Since edge detection is one of the primitive steps of image recognition, it is very important to know the difference between different edge detection algorithms. In Biomedical field, these techniques have huge impact. Also this facilitates us to know which algorithm to apply in which circumstance. Here, through this comparative study,both visual and mathematical analysis has been done.

4.1 Visual Analysis

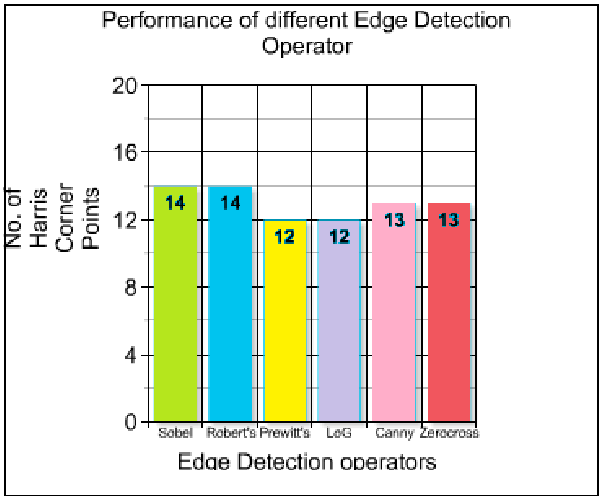
After performing edge detection on Lena, the conclusion is made that among all six edge detection techniques, Canny operator provides the most accurate result i.e. the edges of the image are continuous and clearly demarcated; thus making the image recognizable. On a contrary, LoG and Zerocross operators detect edges more minutely. But in order to achieve precision, it makes the image discontinuous and the features become less prominent. In case of Sobel, Robert's and Prewitt's operators, neither they provide fine-level precision nor is the output image as recognizable as that of Canny. Thus roughly the conclusion is that in case of portrait or scenery, canny provides best result due to its intelligent way of detecting edges in which it maintains both precision and image identity at the same time. Again LoG, Sobel are the choice for detecting fine-features such as biometric images like retinal fundus image as they contain fine blood vessels.

4.2 Mathematical Analysis

The following table shows the comparative results of the application of Harris Corner Detection algorithm on images obtained as a result of applying different edge detection algorithms:

Operators	# Harris Corner Points
Sobel	14
Robert's	14
Prewitt's	12
LoG	12
Canny	13
Zerocross	13

Graphically it can shown as,



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