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A Comprehensive Analysis of Image Edge Detection Techniques

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Abstract

One of the important objectives of image processing is to interpret the content of image efficiently and finds the meaningful and significant information from it. The much awareness has been received from various researchers in the field of image interpretation. One of the most severe step in image interpretation is to mine the edges information from the image appropriately. Edges are the fundamental features of the image and can be formed from the outlines of the object. Edge detection is generally used in image analysis and processing. There are several types of algorithm to detect the edges. In this paper, the comprehensive analysis is done on the several edge detection techniques such as Prewitt, Sobel, Canny, Roberts and Laplacian of Gaussian. It is experimentally observed that Canny edge detector is working well than others. This work is implemented on Matlab R2015a.

Keywords*: Image segmentation, Edge detection, Prewitt, Sobel, Laplacian of Gaussian, Canny, Roberts, PSNR, SNR*

1. Introduction

Image processing is a method of analyzing and manipulating the digital images with the computer using mathematical operators. In image processing, the input is an image and outcome may be either set of characteristics or set of the parameter of image or an image. An image comprises various information like contour of the object, its orientation, size and color. So, as to find the shape information of the object, the edges involving in that object must be identified. Edge detection is a method to detect the occurrence of edges and its locality which is created by sharp and abrupt variations in intensity (brightness or color) of an image. The discontinuities of an image can be variation in scene illumination, discontinue in scene, surface orientation, its depth and variation in material properties. The objectives of edge detection are to detect the shape information of the object and the reflectance in the image. Edge detection is the important step in image analyzing and processing, computer vision, human vision, object detection and pattern recognition. There are various edge detection techniques for detecting the edges. The different edge detectors work differently. Means some edge detectors take more time and detects more edges with respect to others. The edge detection in an image is rest on intensity, illumination, objects, noise, blur [1] [2] [3].

In this paper, various techniques of edge detection are studied for identifying the edges in an image and the comparative analysis is also performed among these techniques.

2. Edge Detection Techniques

The edge demonstration of the image decreases the amount of information to be processed, which contains vital information about the object's shape in an image.

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Edges are local variations in image intensity. The edge forms between the boundaries of two regions. The main information can be mined from the edge.

Edge detection [2] [4] is a process to locate the edges that having good orientation and it is an essential tool of image segmentation. Edge detection method transforms the original image into edge image with the help of operators. It is a well-known process for identifying the dis-continuities in intensity values. In the process of edge detection, the image is inputted first and converts that image into gray scale image. And then apply the edge detector to detect and extract the edges present within an image as output.

The various techniques are available for detecting the edges information such as Roberts, Prewitt, Sobel, Laplacian of Gaussian and Canny. These techniques are described as follows.

2.1. Roberts Edge Detection

Lawrence Roberts has proposed the Roberts edge detection technique [1] [11] for detecting the edges within an image in 1965. It is a simple and computationally efficient approach. It measures the spatial gradient of an image. The pixel value at that point in the resultant image characterizes estimated absolute magnitude value of the spatial gradient of the inputted image at that point. It takes input image as gray scale image and produces edges involving in that image. The main disadvantages of this technique are that it can’t detect that type of edges which are multiplies of 45 degrees and it is not symmetric. The Robert operator contains the pair of 2x2 convolution masks which are illustrated in Figure 1. One mask is just to other rotated by 90 degrees.

$$\underset{G_x}{\begin{bmatrix} +1 & 0 \\ 0 & -1 \end{bmatrix}} \qquad \underset{G_y}{\begin{bmatrix} 0 & +1 \\ -1 & 0 \end{bmatrix}}$$

Figure 1. Masks used for Roberts Edge Detection Technique

The partial derivative of Robert operator is given as follows:

$$\frac{\partial f}{\partial x} = f(i,j) - f(i+1,j+1) \tag{1}$$

$$\frac{\partial f}{\partial y} = f(i+1,j) - f(i,j+1) \tag{2}$$

This operator produces the position of edges more accurately, but it has the short support of filters which causes vulnerability to noise.

3.2. Prewitt Edge Detection

Prewitt has proposed the Prewitt edge detection technique [1] [6] [9] in 1970. It is a right algorithm to measure the magnitude and orientation of the edges. This technique evaluates the edge directions directly with the maximum response from the mask. It is having 8 directions. But, sometimes most direct directions approximation are not much perfect. This Prewitt operator is just like a Sobel

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operator and easy to implement than Sobel operator but it produces some times noisier results. The pair of 3x3 convolution masks for 8 directions are illustrated in Figure 2. One mask is just to other rotated by 90 degrees.

-1	0	+1
-1	0	+1
-1	0	+1

G_x

+1	+1	+1
0	0	0
-1	-1	-1

G_y

Figure 2. Masks used for Prewitt Edge Detection Technique

The organization of pixels about central pixel is as follows:

$$\begin{vmatrix} a_0 & a_1 & a_2 \\ a_7 & [i-j] & a_3 \\ a_6 & a_5 & a_4 \end{vmatrix}$$

The partial derivatives of Prewitt operator are measured as:

$$G_x = (a_2 + ca_3 + a_4) - (a_0 + 2a_7 + a_6) \quad (3)$$

$$G_y = (a_6 + ca_5 + a_4) - (a_0 + 2a_1 + a_2) \quad (4)$$

The Prewitt edge detector is less vulnerable to noise because it differentiates in one direction and make average in another direction

2.3. Sobel Edge Detection

Irwin Sobel has proposed the Sobel edge detection technique [1] [11] [10] in 1970. The Sobel kernel depends on the central difference, but while averaging it gives more weight to central pixel. One of the advantages of Sobel kernel over Prewit kernel is that it has better noise suppression characteristics. The Sobel edge detection method contains the pair of 3x3 convolution masks illustrated in Figure 3. One mask is just to other rotated by 90 degrees. This mask can deal with the edges which are running 45 degrees to the pixel grid. This mask can be put on distinctly to the input image to give gradient components in every orientation.

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

G_x

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

G_y

Figure 3. Masks used for Sobel Edge Detection Technique

The partial derivatives for Sobel operator are as follows:

$$G_x = (a_2 + 2a_3 + a_4) - (a_0 + 2a_7 + a_6) \tag{5}$$

$$G_x = (a_6 + 2a_5 + a_4) - (a_0 + 2a_1 + a_2) \tag{6}$$

The Gradient magnitude is as follows:

$$|G| = \sqrt[2]{G_x^2 + G_y^2} \tag{7}$$

The Orientation angle is measured as follows:

$$\theta = \arctan\left(\frac{G_x}{G_y}\right) - \frac{3\pi}{4} \tag{8}$$

2.4. Laplacian of Gaussian (LOG) Edge Detection

Marr has introduced the Laplacian of Gaussian (LOG) technique [11] [12] in (1982). LOG is based on second order derivative. Which stated as:

$$\nabla^2 f = \frac{\delta^2 f}{\delta x^2} + \frac{\delta^2 f}{\delta y^2} \tag{9}$$

LOG smoothes the image first then calculate Laplacian. This process produces the double edge image. It locates edges then search the zero crossing between the double edges. The LOG edge detection method contains the pair of 3x3 convolution mask which is illustrated in Figure 4.

+1	+1	+1
+1	-8	+1
+1	+1	+1

G_x

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

G_y

Figure 4. Masks used for LOG Edge Detection Technique

2.5. Canny Edge Detection

John Canny introduced the canny edge detection technique [1] [5] [11] at MIT in 1983. It is the standard, powerful and usually used edge detection method. It separates the noise from the image before extracting edges. Canny is a better method for extracting the edges than other existing methods and produces the good result. The Canny operator can control a number of details of edge image and can suppress the noise efficiently.

This method follows following steps:

1) For smoothing the image, the Gaussian filter is used with the identified value of sigma which reduces noise.

2) At each point, the edge direction and local gradient are calculated. According to edge point, it is the point with locally maximum strength in the gradient direction.

3) The edge point increases ridges in the gradient image magnitude. In this algorithm, top of these ridges are considered and gives zero value to all pixels that are not

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on the ridges top. Then, as output, a thin line is produced. This process is called non-maximum suppression. Then, hysteresis thresholding is used here to threshold the ridges pixel. It has two threshold values such as T1 and T2. Case1: if T1>T2, ridges pixel value is higher than threshold T2, shows strong edge pixels. Case 2 if T2>T1, if T1<T2, ridges pixel value is lesser than threshold T2, shows weak edge pixel.

4) At last, the edge linking process executes by integrating the weak pixels that having 8-pixel connectivity to strong pixels.

The canny edge detection method contains the pair of 3x3 convolution mask shown in Figure 5.

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

G_x

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

G_y

Figure 5. Masks used for Canny Edge Detection Technique

2.6. Parameter Used For Comparison

In this paper, PSNR and MSE are used to measure the performance of each edge detection technique.

2.6.1. Peak Signal to Noise Ratio (PSNR)

PSNR [7] [11] [12] [13] [14] [15] is measured as the ratio of maximum possible power and occurring noise that can disturb the representation of the image. PSNR is measured in decimal scale. To calculate the quality reconstruction of an image, PSNR is used commonly by the various researchers. It is a case where original data is treated as signal and occurring error is treated as noise. The maximum value of PSNR shows high image quality. The PSNR can be expressed as follows:

$$PSNR = 10.\, log_{10}\left(\frac{MAX_1^2}{MSE}\right) \tag{10}$$

Where MAX = Maximum pixel value of image and image is represented by 8 bit/sample.

2.6.2. Mean Square Error (MSE)

MSE [8] [11] [12] [13] measures the true pixel value of usual information with the degraded picture, it is used for the realistic purpose. Generally, MSE is calculated as the average of square of the error between the genuine image and noisy image. The error can me estimated as the difference between genuine image and degraded image. Here, lesser value of MSE shows high and best quality image.

$$MSE = \frac{1}{N}\|x - x'\|^2 = \frac{1}{N}\sum_{i=1}^{N}(x - x')^2 \tag{11}$$

3. Experimental Results

The experiment is done on Matlab R2015a and tested with the Sunflower and Face image. To extract the clean edges map by using the principle edge feature of image is our objective. Here various experiments, to detect and extract the edges, have been done with the noise and without noise environment. In Figure 6 and Figure 10, the results by applying various edge detection techniques on original image are displayed. In Figure 7 and Figure 11, the results by applying various edge detection techniques on Salt and Pepper noise effected image are shown. In Figure 8 and Figure 12, the results by applying various edge detection techniques on Gaussian noise effected image are shown. In Figure 9 and Figure 13, the results of Speckle noise effected image by applying various edge detection techniques are shown.

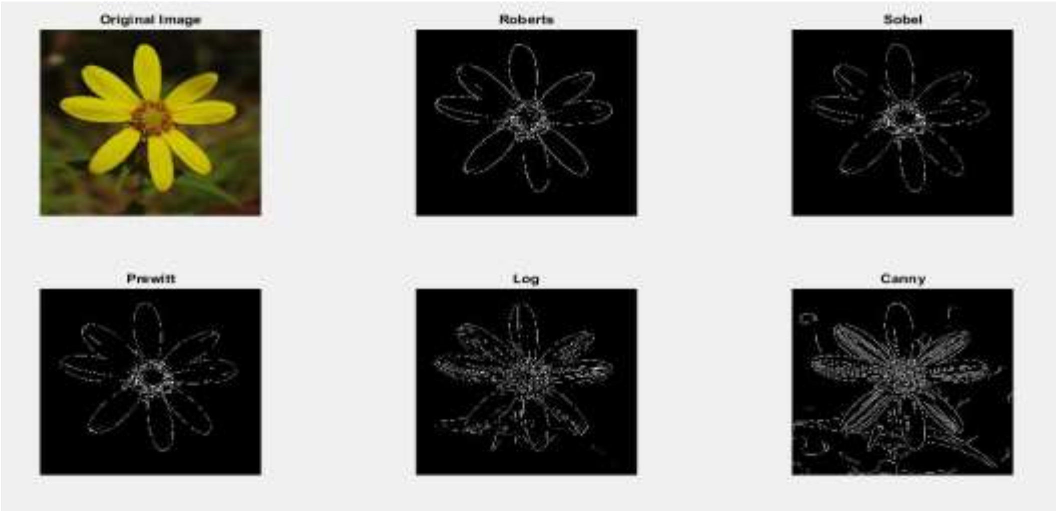

Figure 6. Original Sunflower Image with the Outcome of Different Edge Detection Techniques

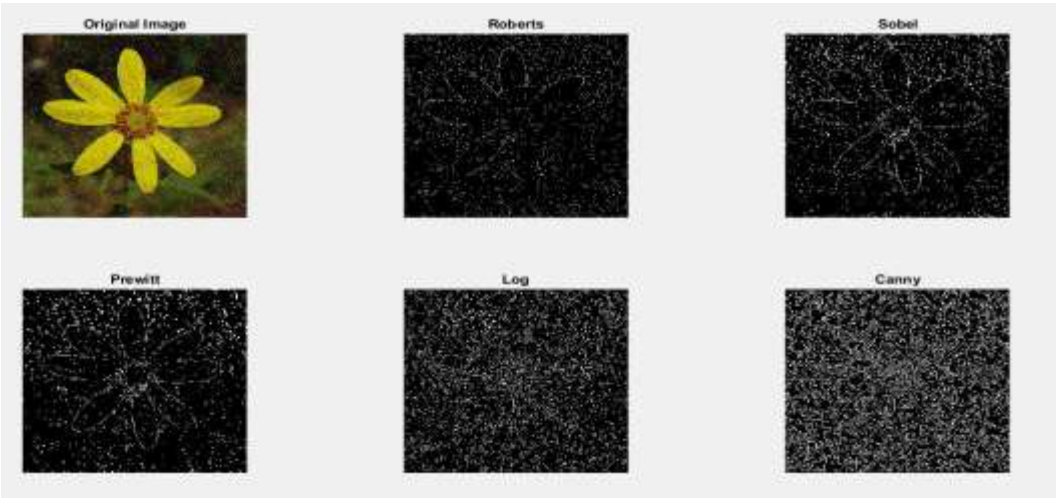

Figure 7. Salt & Pepper Noise Effected Sunflower Image with the Outcome of Different Edge Detection Techniques

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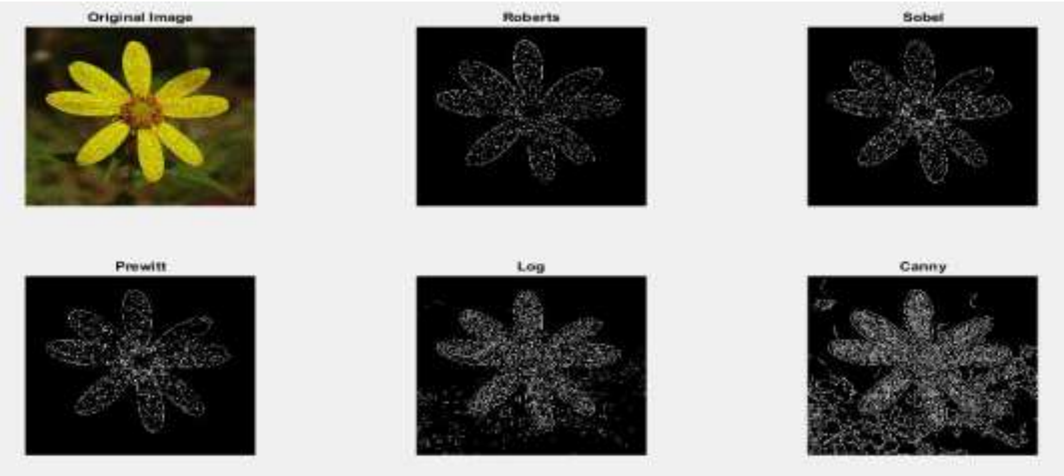

Figure 8. Gaussian Noise Effected Sunflower Image with the Outcome of Different Edge Detection Techniques

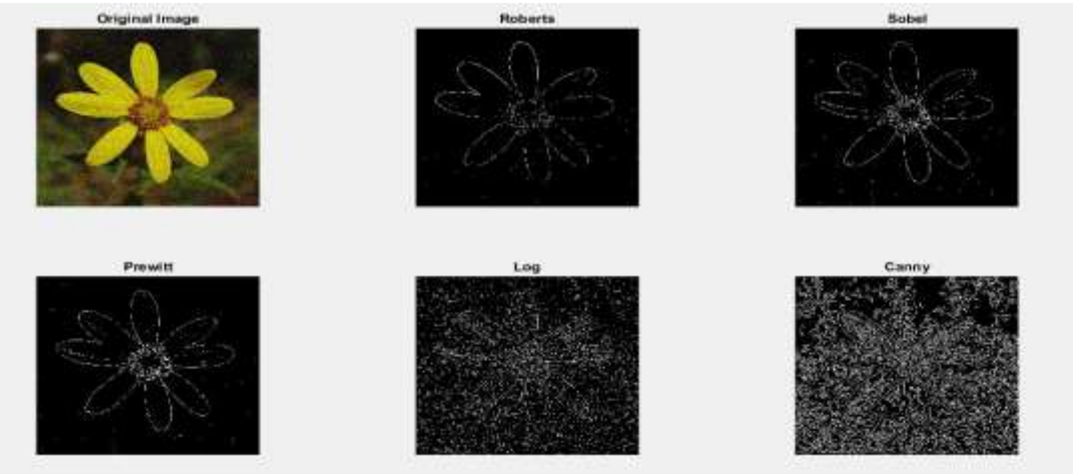

Figure 9. Speckle Noise Effected Sunflower Image with the Outcome of Different Edge Detection Techniques

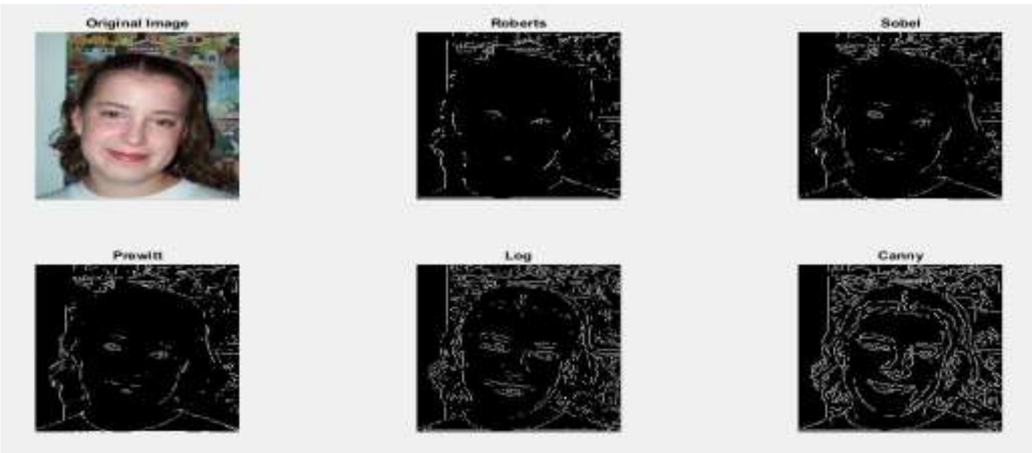

Figure 10. Original Face Image with the Outcome of Different Edge Detection Techniques

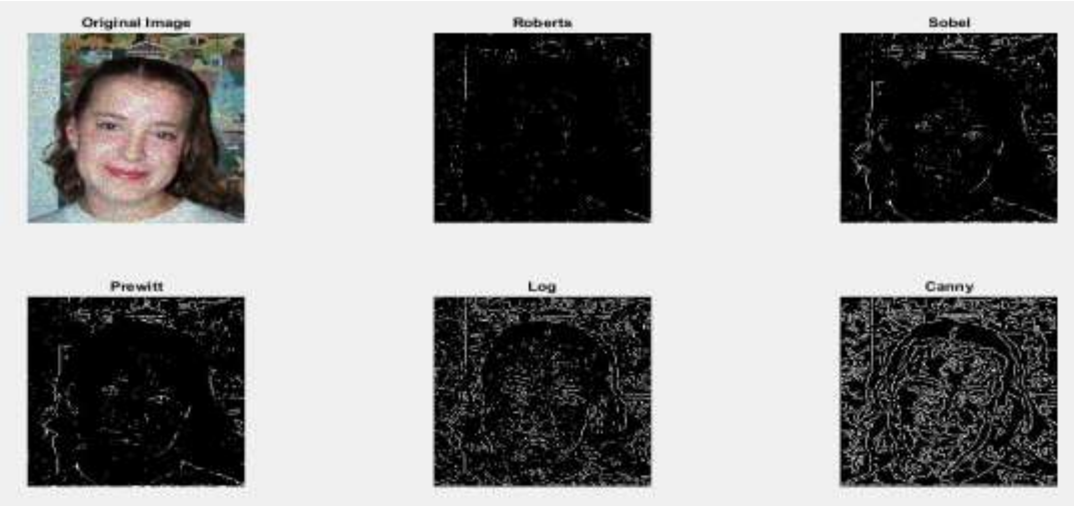

Figure 11. Salt & Pepper Noise Effected Face Image with the Outcome of Different Edge Detection Techniques

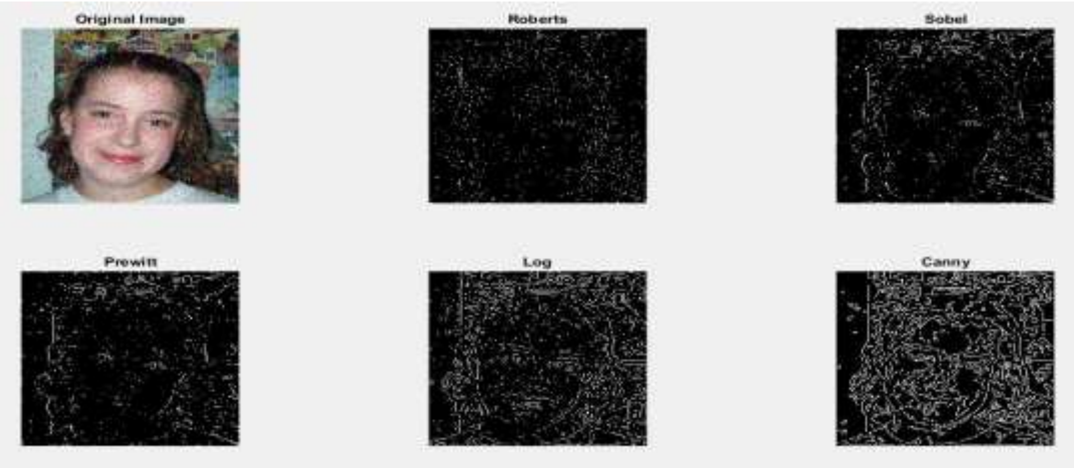

Figure 12. Gaussian Noise Effected Sunflower Image with the Outcome of Different Edge Detection Techniques

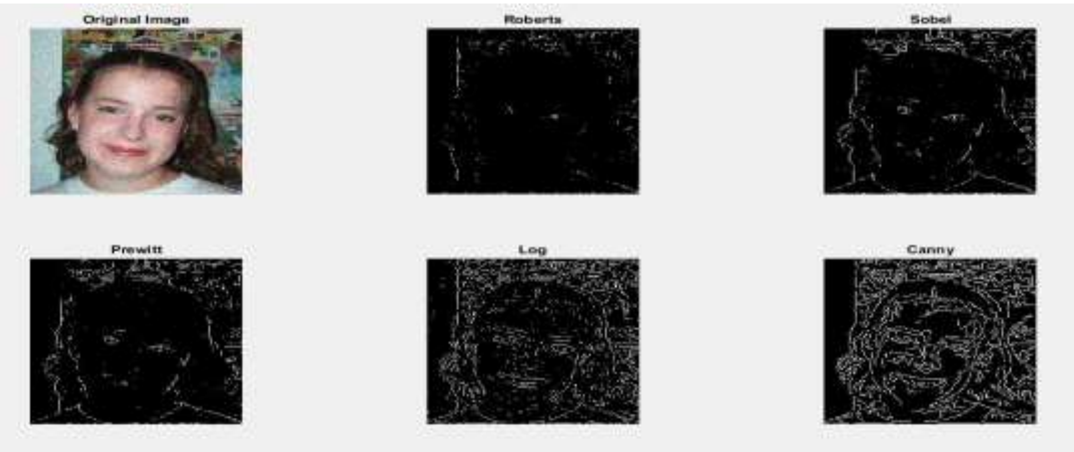

Figure 13. Speckle Noise Effected Sunflower Image with the Outcome of Different Edge Detection Techniques

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Here, Table 1 illustrated the PSNR and MSE value for the results of various edge detection techniques on Sunflower Image in present of noise and no noise. Table 2 illustrated the PSNR and MSE value for the results of various edge detection techniques on Face Image in present of noise and no noise. Table 3 describes the advantages and disadvantages of the edge detection techniques.

Table 1. PSNR and MSE Value for Various Edge Detection Techniques on Sunflower Image

Edge detection Techniques	Original Sunflower Image		Salt & Pepper Noise Effected Sunflower Image		Gaussian Noise Effected Sunflower Image		Speckle Noise Effected Sunflower Image	
	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE
Roberts	9.0044	8.177e+03	8.6962	8.779e+03	8.7929	8.586e+03	8.9127	8.352e+03
Sobel	9.0042	8.177e+03	8.6965	8.778e+03	8.7937	8.584e+03	8.9137	8.350e+03
Prewitt	9.0042	8.178e+03	8.6965	8.778e+03	8.7937	8.584e+03	8.9135	8.350e+03
LOG	9.0072	8.178e+03	8.7024	8.766e+03	8.8001	8.571e+03	8.9184	8.341e+03
Canny	9.0098	8.167e+03	8.7087	8.754e+03	8.8077	8.556e+03	8.9236	8.331e+03

Table 2. PSNR and MSE Value for Various Edge Detection Techniques on Face Image

Edge detection Techniques	Original Face Image		Salt & Pepper Noise Effected Face Image		Gaussian Noise Effected Face Image		Speckle Noise Effected Face Image	
	PSNR	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**
Roberts	5.6363	1.776e+04	5.6017	1.791e+04	5.5976	1.801e+04	5.5908	1.794e+04
Sobel	5.6364	1.776e+04	5.6024	1.791e+04	5.5982	1.801e+04	5.5918	1.794e+04
Prewitt	5.6365	1.776e+04	5.6023	1.791e+04	5.5982	1.801e+04	5.5918	1.794e+04
LOG	5.6383	1.775e+04	5.6057	1.770e+04	5.6015	1.800e+04	5.5958	1.792e+04
Canny	5.6395	1.774e+04	5.6080	1.779e+04	5.6038	1.799e+04	5.5992	1.791e+04

Table 3. Advantage and Disadvantage of Different Edge Detection Techniques

Edge Detection Techniques	Advantage	Disadvantage
Roberts (Based on First Order Derivatives)	Produces more accurate position of edges	Not reliable to extract the edge in presence of noise
Sobel (Based on First Order Derivatives)	Good noise suppression characteristics	Produce moderate result
Prewitt (Based on First Order Derivatives)	Masks have longer support, Prewitt is less vulnerable to noise	Produce sometimes noisier result
LOG (Based on Second Order Derivatives)	Having fixed characteristics in all the directions, detects good edges and its orientations	Sensitive to noise, generate closed and non-realistic contour
Canny (Based on Second Order Derivatives)	Better detection specially in noise condition	Complex, time consuming, false zero crossing

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5. Conclusion

In this paper, various edge detection techniques are studied and compared. After the experimental analysis, it is found that the second order derivatives (Canny and Log) is working well in comparison to first order derivatives (Sobel, Prewitt and Roberts). The Log and Canny edge detection method producing good results for image quality and visual perception. Since, Log edge detection technique is vulnerable to noise. So, it is not providing the better results than canny edge detection technique in presence of noise. Hence, it is experimentally proved that the canny edge detector is a better edge detector technique of forming the edges for inner as well as outer lines of the object. It has more good resistance to noise than Roberts, Prewitt, Sobel and Log edge detection technique. Here, Sobel edge detection technique proves better for discovering better outer lines (continuous boundary) only of an object. As the future work, we can design the new filter over the limitation to get better image quality so that the image can be enhanced by reducing the noise.

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