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Performance Comparison of Different Feature Detection Methods with Gabor Filter

Harpreet Kaur[1], Lakhwinder Kaur[2]

[1,2] Department of Computer Engineering, Punjabi University, Patiala, Punjab, India

Abstract: ***This paper compares the performance of different edge detection methods like Sobel, Prewitt, Robert's, Canny, Laplacian, Laplacian of Gaussian with Gabor filter on number of images. It has been concluded that in case of natural images a Gabor filter yields better results than other operators but in case of medical images like CT, PET, MRI, the Canny operator shows better results as it provides fine details of an image.***

Keywords: Feature extraction, Sobel, Robert's, Prewitt, Canny, Laplacian, Laplacian of Gaussian, Gabor filter

1. Introduction

Feature extraction is one of the most frequently used technique in digital image processing. Edge detection is a process of identifying and locating sharp discontinuities in an image[1]. It plays an important role in computer vision and image analysis as edges contains pretty useful and identical information that helps in image recognition[2]. The reason for this is that edges form the outline of an object and it is the boundary between an object and the background. This means that if the edges are identified accurately in an image, the objects of interest can be segmented easily and the basic properties such as area, perimeter, and shape can be measured. Since computer vision involves the identification and classification of objects in an image, edge detection is an essential tool. It is a vital to have a good understanding of an edge detection operators[3-4].

Edges, in images are the areas with strong intensity contrasts. Different methods have been used in the literature like Sobel, Prewitt, Robert's, Canny, Laplacian, Laplacian of Gaussian for edge detection in image processing and each method has their different properties to detect edges in an images[5-9].

Many researchers have worked on the detection of egdes under various lighting conditions [5-13]. These techniques are applied on medical images such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI) which helps doctors to get more accurate clinical information [14-16]. Also, many research papers have been published in literature for various applications of Gabor filter, in an image processing[17-18]. Gabor filter was also used for feature extraction on face images and yielded better results [19].

2. Methods of Edge Detection

Edge detection methods are implemented with discrete approximations of differential operators using convolution mask. Differential operations measure the rate of change in the image brightness function. Some operators return orientation information and other return information only about the existence of an edge at each point.

2.1 First Order Derivative / Gradient Methods

The gradient vector(G) of a 2-D function *f*(x,y), is defined as the derivatives of vector components given in the horizontal(G_x) and vertical(G_y) directions.

$$G = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial f / \partial x \\ \partial f / \partial y \end{bmatrix} \quad (2.1)$$

The magnitude of gradient vector is specified by:

$$|G| = \sqrt{G_x^2 + G_y^2} \approx |G_x| + |G_y| \quad (2.2)$$

The angle of gradient vector is given by:

$$\theta = \tan^{-1}(G_y / G_x) \quad (2.3)$$

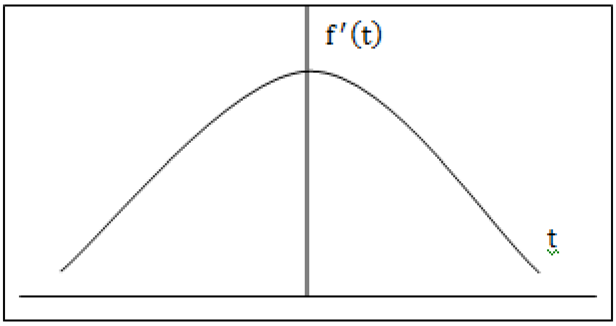

Figure1: First Order Derivative Slope [22]

At each image point, the gradient vector points in the direction of largest possible intensity increase, and the length of the gradient vector corresponds to the rate of change in that direction[27]. The different first order derivatives are given below:

a) Roberts Operator
b) Sobel Operator
c) Prewitt Operator

2.1.1 Roberts Edge Detector

Roberts Edge Detector is a 2-D spatial gradient measurement on an image. It highlights regions of high spatial frequency which often correspond to edges. Pixel values at each point in the output, represent the estimated absolute magnitude of the spatial gradient of the input image at that point [21].

+1	0		0	+1
0	-1		-1	0
G_x			G_y	

Figure2: Roberts convolution mask [22]

Primary disadvantage

- High sensitivity to noise.
- Few pixels are used to approximate the gradient.

2.1.2 Sobel Edge Detector

It computes a 2-D spatial gradient measurement on an image and emphasizes regions of high spatial frequency that correspond to edges. Usually it is used to find the approximate absolute gradient magnitude of an input grayscale image at each point. The discrete computation of the partial derivation is approximated in digital images by using the Sobel operator, which is shown in the masks below:

-1	0	+1		+1	+2	+1
-2	0	+2		0	0	0
-1	0	+1		-1	-2	-1
G_x				G_y		

Figure 3: Sobel convolutions mask [3].

Advantages

- It is less susceptible to noise.

Disadvantages

- It produces thicker edges. So edge localization is poor in case of images having fine details.

2.1.3 Prewitt Edge Detector

This operator is an appropriate way to estimate the magnitude and orientation of an edge in an image. Although differential gradient edge detection needs a rather time consuming calculation to estimate the orientation from the magnitudes in the x and y-directions, the compass edge detection obtains the orientation directly from the kernel with the maximum response. The Prewitt operator is limited to 8 possible orientations. This gradient based edge detector is estimated in the 3x3 neighborhoods for eight directions. One convolution mask which yielded maximum response is selected at each point [22].

-1	0	1		1	1	1
-1	0	1		0	0	0
-1	0	1		-1	-1	-1
G_x				G_y		

Figure 4: Prewitt convolution mask [3]

2.2 Second Order Derivative

The second order derivative of a 2-D function $f(x,y)$, is defined as the derivatives of vector components given in the horizontal(G_x) and vertical(G_y) directions as follow:

$$\frac{\partial^2 f}{\partial x^2} = f(x+1,y) + f(x-1,y) - 2f(x,y) \quad (2.4)$$

$$\frac{\partial^2 f}{\partial y^2} = f(x,y+1) + f(x,y-1) - 2f(x,y) \quad (2.5)$$

The different second order derivatives are given below:
a) Laplacian operator
b) Laplacian of Gaussian operator

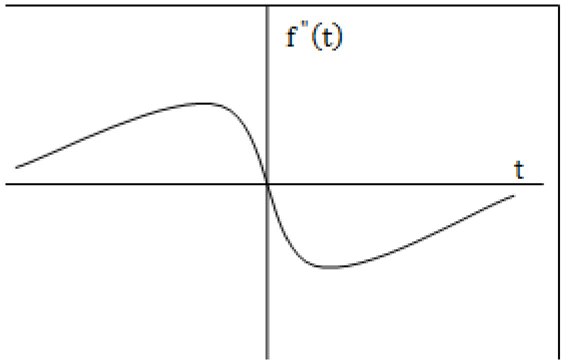

Figure 5: Second Order Derivative Slope [22]

2.2.1 Laplacian Operator

Laplacian operator of an image highlights regions of rapid intensity change and often used for edge detection. The Laplacian often applied to an image that has been first smoothed with Gaussian smoothing filter in order to reduce its sensitivity for noise. This operator generally takes a single gray level input image and produces another gray level output image. The Laplacian operator($\nabla^2 f$) combines the second order derivatives as follows:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad (2.6)$$

Enhanced image is denoted as g(x,y).

$$g(x,y) = f(x,y) + \nabla^2 f(x,y) \quad (2.7)$$

If center coefficient of mask is negative.

$$g(x,y) = f(x,y) - \nabla^2 f(x,y) \quad (2.8)$$

If center coefficient of mask is positive.

0	1	0		1	1	1		−1	2	−1
1	−4	1		1	8	1		2	−4	2
0	1	0		1	1	1		−1	2	−1

Figure6: Laplacian convolution mask (adopted from [21])

Response of Laplacian operator

- Zero signals the presence of an edge.
- Trivial zeros (uniform regions are ignored).

Properties of Laplacian operator

- It is an isotropic operator.
- It does not provide information about edge direction.
- It is more sensitive to noise (i.e. differentiates twice).

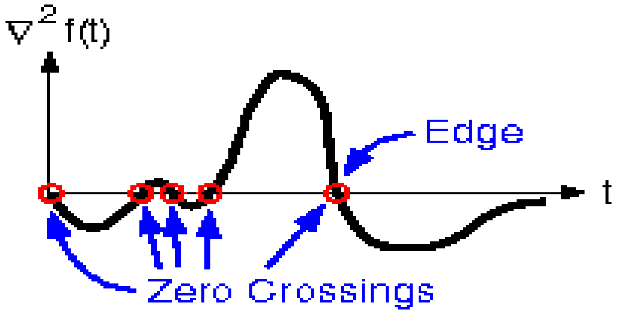

Figure7: Edge representation with zero crossing points (adopted from [5]).

b) Laplacian of Gaussian

The LoG operator calculates the second spatial derivative of an input image, it means that areas where the image has a constant intensity (i.e. where the intensity gradient is zero), the LoG response will be zero. Laplacian of Gaussian will be response lighter side in case of the change in an intensity area. Once the image has been LoG filtered, it only remains to detect the zero crossings. It can be done in several ways. This operator is also known as Marr-Hildreth Edge Detector or the Mexican Hat operator. In this approach, an image should first be convolved with Gaussian filter.

$$g(x,y) = \nabla^2[G(x,y,\sigma) * f(x,y)] \quad (2.9)$$

Laplacian of Gaussian has the following expression:

$$\mathrm{LoG}(x,y) = -\frac{1}{\pi\sigma^4}\left[1-\frac{x^2+y^2}{2\sigma^2}\right]e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2.10)$$

The simplest way is to threshold the LoG output at zero, to produce a binary image where the boundaries between background and foreground regions represent the locations of zero crossing points. These boundaries then can be easily detected. For example, to locate all boundary points, users simply have to mark each and every foreground point that has at least one background neighbor.

2.3 Optimal Edge Detection

2.3.1 Canny Edge Detector

Canny Edge Detector technique is very important for detecting edges in an image. This operator isolates noise from an image before finding, edges of an image without affecting the features of the image, and then applying the tendency to find the edges and the critical value for threshold.

Optimal edge detector depending on three criteria

- Low error rate – edges should not be missed and there must not be spurious responses.
- Localization – distance between points marked by the detector and the actual center of the edge should be minimum.
- Response – Only one response to a single edge.

Advantages

- Using probability for finding error rate.
- Localization and response.
- Improving signal to noise ratio.
- Better detection especially in noise conditions.

Disadvantages

- Complex Computations.
- False zero crossing problem.
- Time consuming.

3. Gabor filter

Gabor filter is a linear filter used in image processing for edge detection. Its frequency and orientation representations are similar to the human visual system, and they have been found to be particularly appropriate for texture representation and discrimination. 2-D Gabor filter is a Gaussian kernel function modulated by a sinusoidal plane wave in a spatial domain [20].

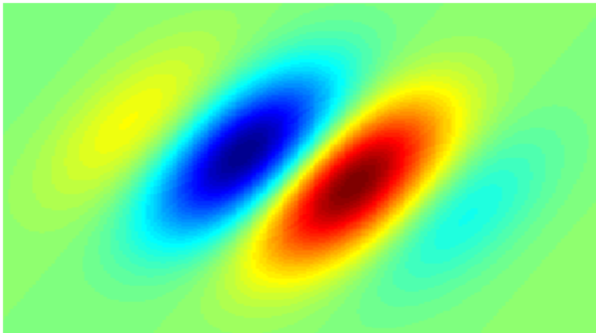

Figure8: A two-dimensional Gabor filter(adopted from[20])

Gabor filters are self-similar and all filters can be generated from one mother wavelet by performing dilation and rotation. A filter bank consisting of various scales and orientations of Gabor filters is created. The filters are convolved with the signal and the Gabor space is obtained as a result of that. The filter has a real and an imaginary component representing orthogonal directions. The two components may be formed into a complex number or used individually. Complex one is

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma) = \exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right)\exp\left(i\left(2\pi\frac{x'}{\lambda}+\psi\right)\right) \quad (3.1)$$

Real part is

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma) = \exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right)\cos\left(2\pi\frac{x'}{\lambda}+\psi\right) \quad (3.2)$$

Imaginary part is

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma) = \exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right)\sin\left(2\pi\frac{x'}{\lambda}+\psi\right) \quad (3.3)$$

Where

$$x' = x\cos\theta + y\sin\theta \quad (3.4)$$

And

$$y' = -x\sin\theta + y\cos\theta \quad (3.5)$$

In the above equations, λ represents the wavelength of the sinusoidal factor, θ represents the orientation of the normal to the parallel stripes of a Gabor function, ψ is the phase offset, σ is the standard deviation of the Gaussian envelope and γ is the spatial aspect ratio. Its impulse response is defined by a harmonic function multiplied by a Gaussian function. Because of the multiplication-convolution property (Convolution theorem), it can be viewed as a sinusoidal plane of particular frequency and orientation, modulated by a Gaussian envelope in a wavelet form. The Gabor transform of an image F(x,y) is defined as the convolution of a Gabor filter g(x,y) with image f(x,y) (Lu et al., 1991):

$$F(x,y) = g(x,y) * f(x,y) \tag{3.5}$$

$$F(x,y) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} g(m,n).f(x-m,y-n) \tag{3.6}$$

Where * denotes two-dimensional linear convolution and M and N are the size of the Gabor filter mask[25-26].Besides edge detection, Gabor filters are successfully used in many other images processing and analysis domains, such as image smoothing, fingerprint recognition, iris recognition, texture analysis, shape analysis and face recognition etc [24].

4. Methodology

The flowchart of the implemented approach is given below:

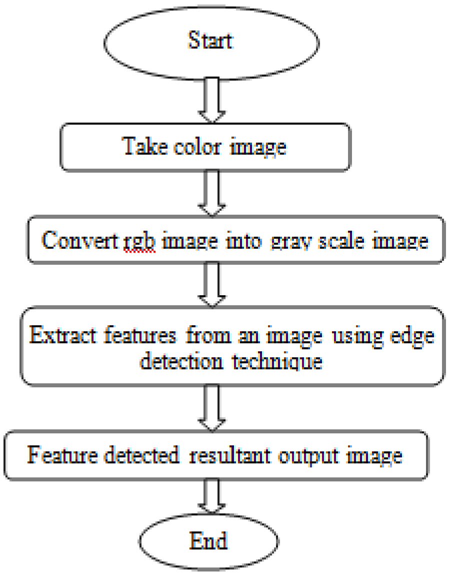

Figure 9: Flow diagram of feature detection method.

5. Results and Discussions

This section presents the implementation and the performance comparisons, among the various edge detection methods, based on visual perception. GUI (Graphical User Interface)[23] named Feature_Detection has been designed in MATLAB software using GUIDE tool. GUIDE tool contains various push buttons and coding of different techniques has been done on these buttons. GUI contains various edge detection operators and Gabor filter as shown in Figure11. The various operators Sobel, Roberts, Prewitt, Zero crossing, LOG, Canny and Gabor filter are applied on an input image(right side top) and their corresponding results are shown on output image(right side bottom) as shown in Figure12 for example using canny operator.

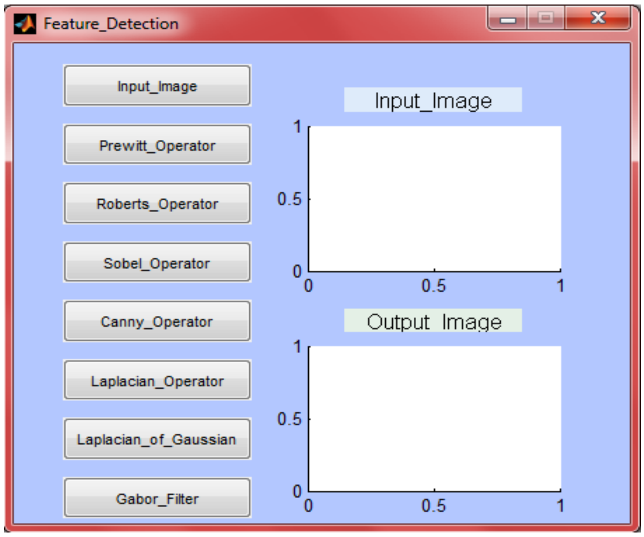

Figure10: This window contains various edge detection methods and graph axes for input image & output image.

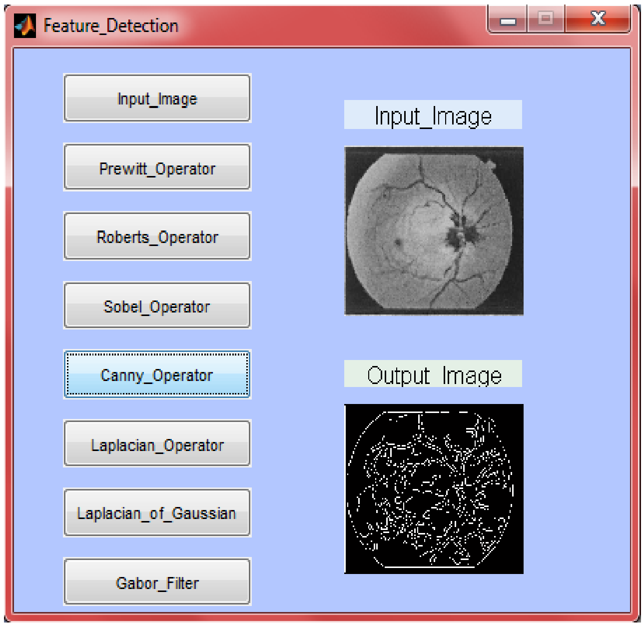

Figure11: This window contains various edge detection methods and output image of canny operator on graph axes for given input image

The relative performance of various edge detection methods are compared based on the better visual outcome of the output images. For comparison of Gabor filter with other operators, the optimal values of its various parameters have been chosen , that are as: lambda = 2, theta= 45, psi = [0 pi/2], gamma= 0.5, bandwidth = 1, N= 8. The original images are shown in Figures(12(a)-19(a)) and the corresponding resulted output images are shown in Figures(12-19)(b) to (h). It have been observed that the Robert's operator detect edges only when there is a sharp change in intensity value and doesn't detect edges when small change in grayscale value and detected egdes are thin. Sobel operator detects more edges as compare to Robert's operator as they response on average change in intensity value. Sobel operator also gives thin edges and we don't get detail information. Prewitt operator, is more sensitive to horizontal and vertical edges. Prewitt operator also responses on average change in intensity value and detect more edges as compare to Robert's operator. One-dimensional operator like Roberts, Sobel and Prewitt are susceptible to noise interference that makes them unable to detect true weak edges. LoG often detects the edge of double pixels wide therefore, it is rarely directly used for edge detection. It is mainly used to determine if the pixels of image are in the dark areas or bright area of the known edge. It detects edges in an image when there is a dramatic change of gray-scale (strong edge) and points with slight change of grayscale as shown in figures(12(f-g)-19(f-g)). Thus these two thresholds are used to detect strong edges and weak edges. Both Laplacian and LoG gives thin edges. But in case of natural images by using Laplacian operator it is difficult to get the correct information of an object as shown in figure12(f). Canny algorithm is not susceptible to noise interference that enables it to detect true weak edges. It's optimal edge detection algorithm means it should mark all possible edges. Canny operator detects edges based on three criteria as discussed above and detects most of the edges from an image as shown in figures (12(e)-19(e)) and this shows that it contains fine details of an image. Canny also provides thin edges. Gabor filter is better feature detection method in case of that images in which we want to see the distinguish feature of images and not interested in its background features. Gabor filter produces thick edges as shown in Figures(12(h)-19(h)). In case of human beings we are interested to detects edges of eyebrows, eyes, nose and mouth without highlights the face details such as skin texture etc. in that case we uses Gabor filter for better results. Gabor filter gives better results than Canny in case of natural images but in medical images Canny operator yields better result as it provides fine details of an image.and Canny edge detector produces higher accuracy in detection of objects as compared to Sobel, Roberts, Prewitt, Zero crossing and LOG.

Figure12:-a)Original Image(face.png) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

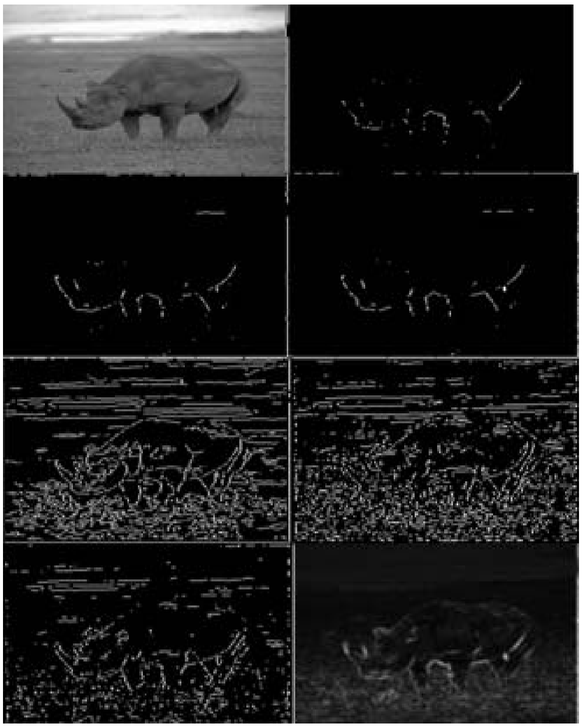

Figure13:-a)Original Image(animal.png) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG Gaussian h)Gabor Filter

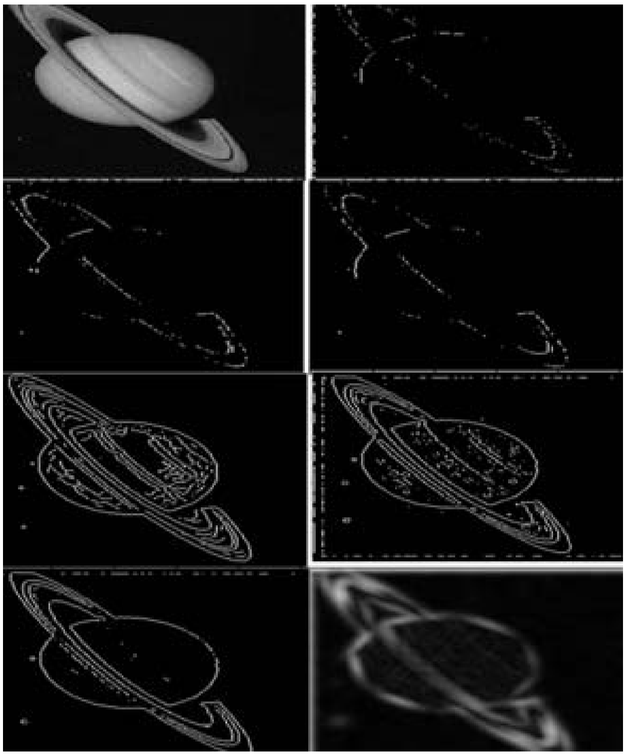

Figure14:-a)Original Image(planet.jpg) b)Robert's c) Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

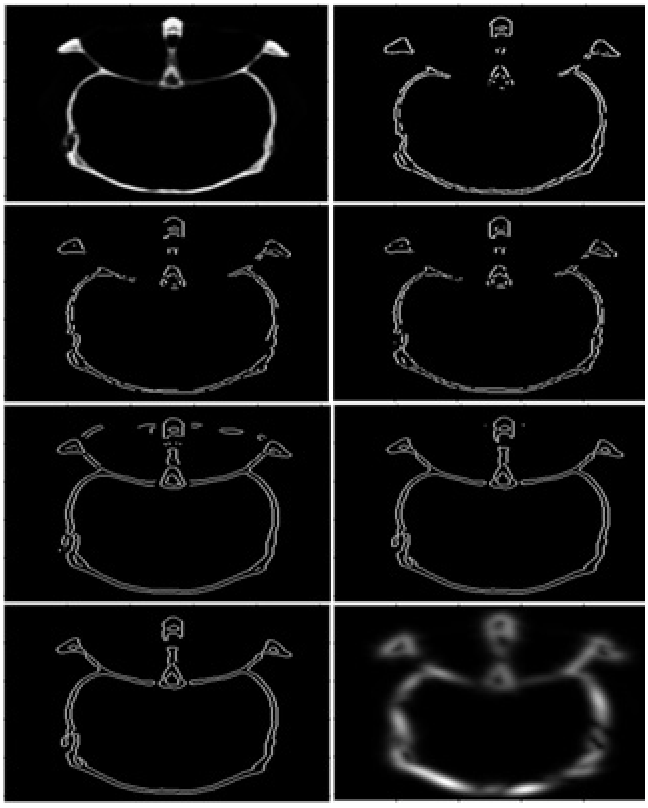

Figure15:-a)Original Image(ct.png) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

Figure16: a)Original Image(house.png) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

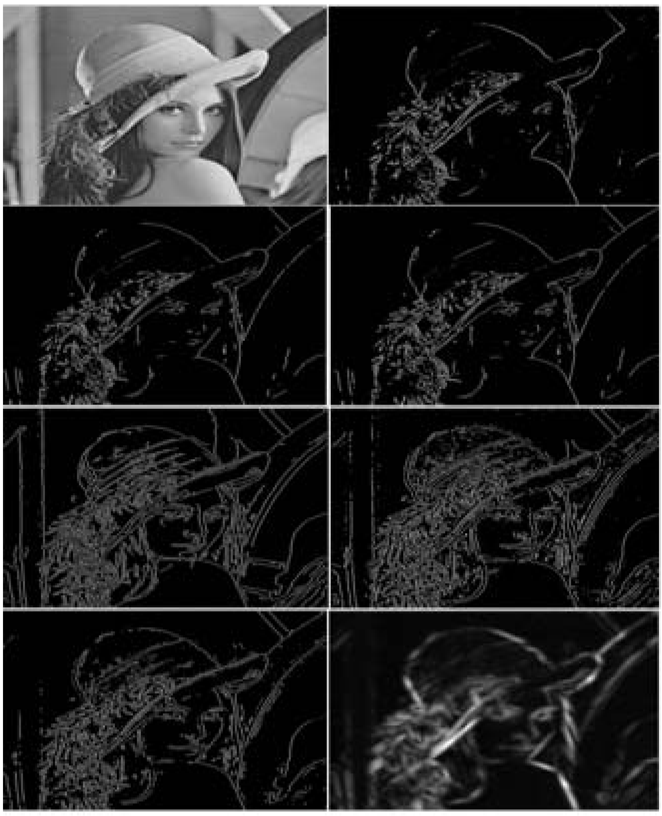

Figure17: a)Original Image(leena.jpg) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

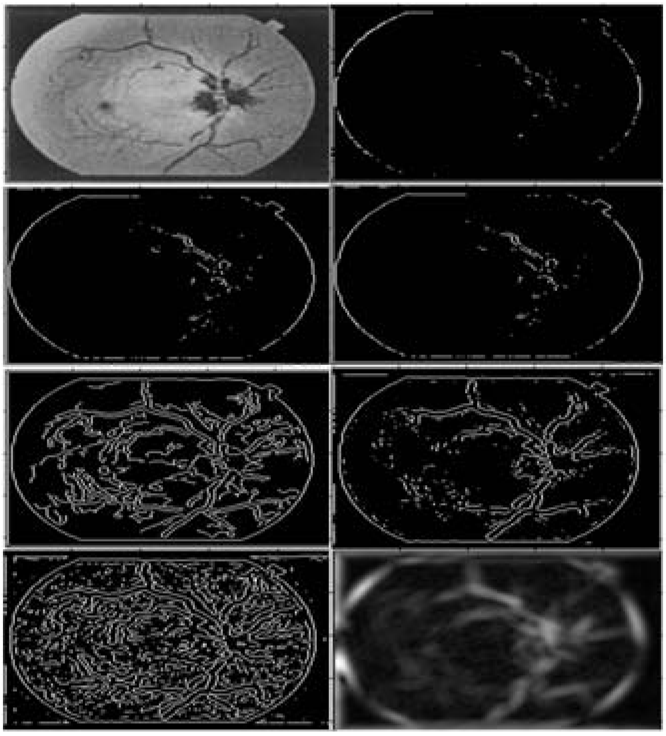

Figure18: a)Original Image(retina.tif) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

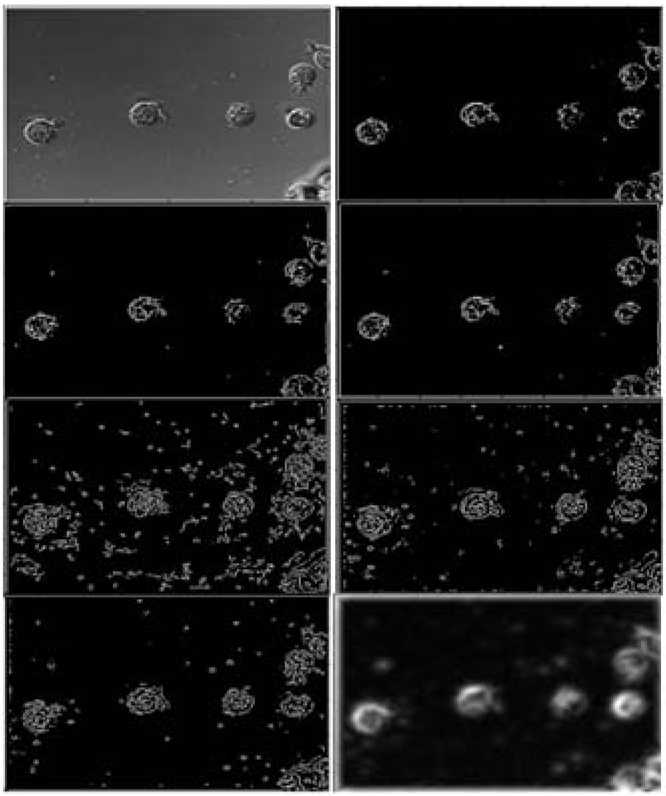

Figure19:a)Original Image(micro.png) b)Robert's c)Sobel d)Prewitt e)Canny f)Laplacian g)LOG h)Gabor Filter

6. Conclusion

In this paper, the comparative study has been done among the different edge detection methods. The effectiveness of the algorithms is evaluated for natural and medical images. Generally Gabor filter gives better results than Canny, especially for natural images, where the objects are considered to be a big challenge to segment. In case of human beings Gabor filter provides better result as the selected parameters produce the large magnitude and brighter intensity of the edges. However, this filtering step does not give proper shapes of object but it produces unique patterns for different object expressions and produce thicker edges as discussed. But in case of medical images the Canny operator yields better results as it provides fine detail of an image and that details are essential in medical field.

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