Performance Evaluation and Comparative Analysis of Various Thresholding Methods and Edge Detection Techniques

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Abstract-**Edge detection plays a very important role in computer technology and image processing. It is used in image processing basically for detection and extraction of edges from any given image. Edge is the point where image brightness changes very sharply or consists discontinuities. It filters out unimportant data, noise even without affecting the structural properties of image. There exists no universal edge detection method which works well under all conditions. In this paper two thresholding techniques are compared against some existing edge detection techniques. The dataset used for comparing consists of six different test images. The performance evaluation is based on visual inspection as well as on quantitative parameters of the resulting images. It has been observed that Otsu and niblack's thesholding methods provide better edge detection results as compared to sobel, prewitt and canny edge detectors.**

Keywords: **Sobel edge detector, Prewitt edge detector, Canny Edge Detector, Otsu's thresholding method, Niblack's method**

I. Introduction

It is a fundamental tool used in most applications of image processing such as feature detection and extraction. Important features can be extracted from the edges of an image (e.g., corners, lines, curves).Edges are detected on the basis of relationship a pixel has with its neighbor pixel's. Any pixel is said to be an edge if its surrounding gray values are rapidly changing. Thus in edge detection edges are identified on the basis of pixel variations in an image. This process detects outlines of an object and boundaries between objects and the background in the image. Thus helps in extracting the basic shape of an image, ignoring the unnecessary details. Edges are detected on the principle of finding sharp discontinuities in images. The sharp discontinuities are immediate changes in brightness of digital image which distinguish boundaries of objects in a scene. Edges of the image is the most significant part which is used generally for image analysis[6].There exists many edge detection techniques such as sobel edge detector, Prewitt edge detector and canny edge detector. This paper presents a quantitative study of various edge detection methods and thresholding techniques. Edge detection methods like, sobel, prewitt and canny are studied and compared with two thresholding techniques i.e., Otsu's method and Ni black's method. Comparison is done on the basis of results produced by implementing these methods on different test images. Results are compared on the basis of visual inspection and the performance measure parameters such as Mean Square Error (MSE), Peak Signal-to-Noise Ratio (PSNR).These methods behave differently depending upon different situations. Their behavior varies according to various components like lighting conditions, density of edges in the scene and noise present at the time of image analysis. We studied three edge detectors and two thresholding techniques on various images to compare their results so that we can analyze which method gives better results.

II. Edge Detection

Edge detections is an essential tool for identification and classification of objects in an image. Edge is the point where there is a significant change in image intensity or contrast. If the edges in an image can be identified accurately, all of the objects in any given image can be located and basic properties such as area, perimeter, and shape can be measured [1]-[3].There are many edge detectors for detection and extraction of various edges in any given image, some of those are Sobel, Prewitt and Canny edge detectors.

A. Sobel Edge detector

Sobel operator is used in image processing for edge detection. It is a gradient based method. It finds the gradient of the image intensity at each point in the given input gray scale image. It is responsible for calculating how likely it is possible to consider that part of image as an edge on the basis of changes at that point such as smooth or more sharp. It also calculates the direction in which that edge is likely to be oriented. Hence it examines the intensities and then gives the direction in which there is largest possible increase from light to dark pixels. As the images are not continuous, we use two kernels for convolution to approximate the gradient derivative. The Sobel edge detector uses a pair of 3x3 convolution masks, one estimating the gradient in the x-direction (columns) and the other estimating the gradient in the y-direction (rows).Two 3x3 convolution masks are used such that one estimates the gradient in x-direction (columns) and other estimating the gradient in y-direction (rows). These two designed to respond maximally to edges running vertically and horizontally relative to the pixel grid.

The actual Sobel masks are shown below:

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

Gx

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

Gy

The magnitude of the gradient is then calculated using the formula:

$$|G| = \sqrt{Gx^2 + Gy^2} \quad .. \quad . \qquad (1)$$

An approximate magnitude can be calculated using:

$$|G| = |G_x| + |G_y| \quad .. \quad . \qquad (2)$$

The angle of orientation gives the gradient's direction is given by[19] :

$$\theta = \arctan\left(\frac{G_y}{G_x}\right) \quad .. \quad . \qquad (3)$$

B. Prewitt Edge Detector

Prewitt operator similarly performs a 2D spatial gradient measurement on a given gray scale image. Like Sobel it is also a gradient based method. It also examines the largest possible increase from light to dark pixels. Hence on the basis of it consider that part of image as an edge where changes occur more abruptly. It also uses two 3x3 convolution mask or kernel. The kernel is almost similar to the Sobel operator except for the weights assigned to the center pixels. The kernel is shown below:

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

Gx

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

Gy

The *x*-coordinate is defined here as increasing in the right-direction and the *y*-coordinate is defined as increasing in the down-direction[20].At each point in the image, the resulting gradient approximations can be combined to give the gradient magnitude, using:

$$|G| = \sqrt{Gx^2 + Gy^2} \quad .. \quad . \qquad (4)$$

An approximate magnitude can be calculated using:

$$|G| = |G_x| + |G_y| \quad .. \quad . \qquad (5)$$

C. Canny Edge Detector

The canny edge detector is a multistage optimal edge detector. It is more widely considered as the standard algorithm for detecting the edges in a given image. Its main aim is to localize the edges means it marks points as an edge in such a way that there is not much difference between the actual and marked

edges. Secondly it takes care that there is no such situation occurs in which it doesn't respond and it doesn't miss points which are edges. The third thing is that it should mark an edge only once means single response to existing edge in an image.
On the basis of above criteria it performs different steps such as:

- It filters out useless data and noise , hence smoothes the image before detecting edges by using Gaussian filter. This step is involved in edge detection as a preprocessing step.
- In next step the detector calculates the gradient at each point in the image. Generally Sobel is used for finding approximate gradient which helps in finding the edge by detecting the largest increase from light to dark pixels and also direction or orientation. Hence magnitude of gradient is given by eq (1).Direction of gradient is given by eq (3).
- In the next step canny edge detector suppress the non-maxima pixels of edge. Such points where gradient is not maximum are removed and not considered as a part of edge. Therefore we iterate through each pixel and their gradient value as well as the orientation of gradient at each point is checked.
- Once above three steps are covered next thing to do is edge thresholding. In this step detector uses the "hysteresis" method of thresholding. This considers two thresholds low and high. Such that any pixel whose value is above high threshold is considered as an edge and if any other pixel which is nearer to the edge pixel and have value above low threshold is also considered as an edge pixel. But if pixel value is lesser than the low threshold then it is never considered as an edge pixel[17]-[18].

III. Thresholding

It is very important technique used in image processing for image segmentation. It is generally used for background and foreground separation of pixels. In thresholding we consider a threshold value **T** on the basis of which separation is done such that all the pixels whose value is greater than the selected threshold are considered under class 1 and all the pixels whose value is lesser than **T** are considered to belong class 2.
Thresholding may be seen as an operation which involves tests against a function T of the form:

$$T=T[x, y,(p(x, y),f(x, y))] \quad .. \quad . \quad (6)$$

Where f(x, y) is the gray level at the point (x, y) and p(x, y) denotes some local property of the point (such as the average gray level of a neighborhood centered on (x, y).

A thresholded image is given by the expression:

$$g(x,y) = \begin{cases} 0 & f(x, y) < T \\ 1 & f(x, y) >= T \end{cases} \quad .. \quad . \ (7)$$

Thus pixels whose value is 1 considered as a part of object and the pixel with value 0 corresponds to the background pixels. But the main problem with thresholding is 'what will be the value of T' such that there is proper segmentation between the foreground and background pixels. Thresholding can be local or global threshold. If the value of T depends only upon the gray level at that point (x, y) i.e., f(x, y) then it is called global threshold but if threshold value depends upon the value of P(x, y) then this is called the local thresholding [12].We can manually select any threshold value but it takes a very long time. so in this paper two algorithms are used for finding the optimum value of T. The methods used are Otsu's thresholding method and Niblack's thresholding algorithm which are explained below.

A. Otsu's Thresholding Method

Otsu is a parameter less global thresholding binarization method. In this method threshold value is selected from gray-level histograms thus reduction of gray level image to binary image. The basic idea is to find the threshold that minimizes the weighted within-class variance. The idea is same as maximizing the between-class variance. It assumes the histogram or pixel level distribution is bimodal i.e., image to be thresholded contain two classes of pixels (i.e., background and foreground).It tries to find the level or threshold value that achieves the best separation of those two classes so that their combined spread (intra-class variance) is minimal.
An image is a 2D gray scale intensity function, and contains N pixels with gray levels from 1 to L. The number of pixels with gray level i is denoted f_i, giving a probability of gray level i in an image of

$$p_i = f_i / N \quad .. \quad . \quad (8)$$

It is based on the threshold for partioning the pixels of an image into two classes C0 and C1(e.g., objects and background) at grey level t, where : C0 = {1, 1, 2,…, t} and C1 = {t + 1, t +2,….l - 1}.Then, the gray level probability distributions for the two classes are

C0: $p_1/\omega_0(t), \ldots\ldots\ldots\ldots\ p_t/\omega_0(t)$ and
C1: $p_{t+1}/\omega_1(t), p_{t+2}/\omega_2(t), \ldots\ldots\ldots p_L/\omega_1(t),$ (9)

Where $\omega_0\ (t) = \sum_{i=1}^{t} p_i$ ... . (10)

And,

$$\omega_1\ (t) = \sum_{i=t+1}^{L} p_i \quad .. \quad . \quad (11)$$

And sigma's represents the individual class variances which are given by:

$$\sigma_0^2\ (t) = \sum_{i=0}^{t}[i-\mu_0]^2\frac{p(i)}{\omega_{0(t)}} \text{ and,}$$
$$\sigma_1^2\ (t) = \sum_{i=t+1}^{l-1}[i-\mu_1]^2\frac{p(i)}{\omega_{1(t)}} \quad .. \quad . \quad (12)$$

where means for classes c0 and c1 are given by following equations :

$$\mu_0\ (t) = \sum_{i=0}^{t}\frac{ip\ (i)}{\omega_{0(t)}} \text{ and,}$$
$$\mu_1\ (t) = \sum_{i=t+1}^{l-1}\frac{ip\ (i)}{\omega_{1(t)}} \quad .. \quad . \quad (13)$$

Let μ_T be the mean intensity for the whole image. Then it can be written as:

$$\omega_0\mu_0 + \omega_1\mu_1 = \mu_T \quad .. \quad . \quad (14)$$

Hence Between class variance of the thresholded image is defined by Otsu as:

$$\sigma_b{}^2 = \omega_0(\mu_0-\mu_T)^2 + \omega_1(\mu_1-\mu_T)^2 \quad .. \quad . \quad (15)$$

For bi-level thresholding, As we need between-class variance maximized [4] .Otsu stated that the optimal threshold t* is selected as:

t* = Arg Max { $\sigma_b{}^2(t)$ } i.e, 1<t<L .. . (16)

B. Niblack's Thresholding Method

It is one of the local thresholding techniques for segmentation. Niblack method produces most significant results for segmenting text documents. This method is implemented by changing the values of variables depending upon different images to images but keeping one variable i.e., weight k constant[7].The threshold T is computed by using the equation given below :

T = m + k*s ... . (17)

Where m is mean and s stands for standard deviation, k is a constant, which determines how much of the total print object edge is retained, and has a value between 0 and 1[11]. The default value is 0.2 for bright objects and -0.2 for dark objects. Any other number than 0 will change the default value. The value of *k* and the size of the sliding window define the quality of binarization.

IV. Quantitative Parameters

Any processing applied to an image may cause an important loss of information or quality. **Mean Square Error (MSE)** is a measure which calculates the magnitude of error. The goal of MSE is to compare two signals by providing a quantitative score that describes the degree of error between them. The MSE give relatively high weight to large errors. If input image is represented as I(i, j) and output image is represented by K(i, j)[16].Then equation of MSE is given below:

$$\text{MSE} = \frac{1}{m\ n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2 \quad .. \quad . \quad (17)$$

The phrase **peak Signal-to-Noise Ratio** (**PSNR)**, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation.

$$\text{PSNR} = 10.\ log_{10}\left(\frac{MAX_I^2}{MSE}\right)$$
$$= 20.\ log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right)$$
$$= 20.\ log_{10}(MAX_I) - 10.\ log_{10}(MSE) \quad ... \quad (18)$$

Here, MAX_I is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255.The unit of PSNR is dB (decibel). It takes from 0 to infinity. If the value is high, the image quality is high [15].

V. Experimental Results

The paper presents three edge detection and two thresholding techniques for edge detection. Three edge detection methods called sobel, prewitt and canny operators and two thresholding methods called Otsu's and niblack's methods are tested with a variety of representing medical as well as natural images and their corresponding results using these methods, as examples of our experiments six images and their edge detection results are given in Fig 1, 2,3,4,5 and 6, where the results of Fig 1 and 2 shows edge detection on medical images using different methods. Fig 3, Fig 4, Fig 5, Fig 6 shows results of edge detection on smooth, sharp and synthetic images.
The error measure and Peak Signal-to-Noise Ratio are also calculated and compared in this section.

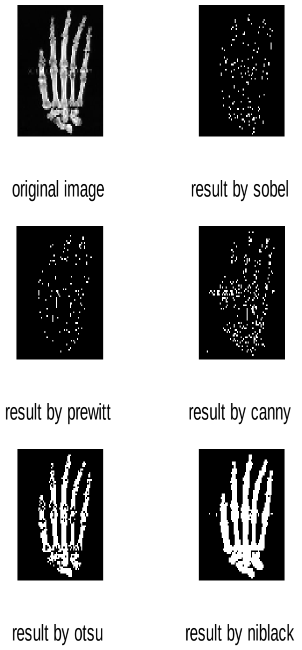

Fig 1 Results of three edge detectors and two thresholding methods on bone structure of human hand

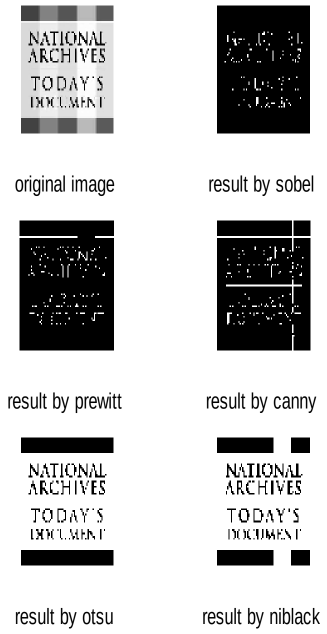

Fig 2 Results of three edge detectors and two thresholding methods on text document

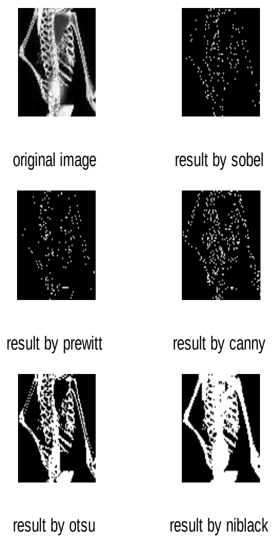

Fig 2 Results of three edge detectors and two thresholding methods on human spine

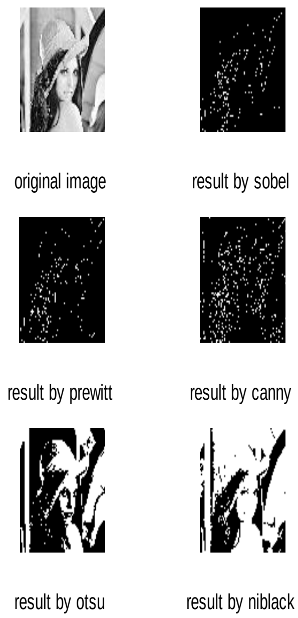

Fig 4 Results of three edge detectors and two thresholding methods

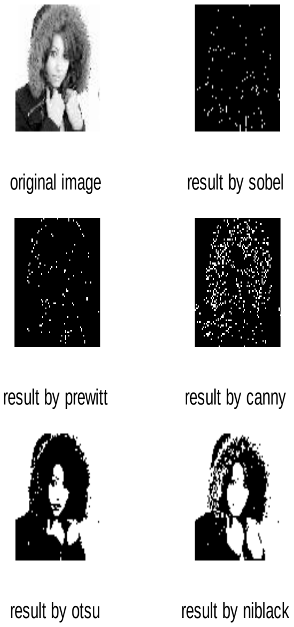

Fig 5 Results of three edge detectors and two thresholding methods

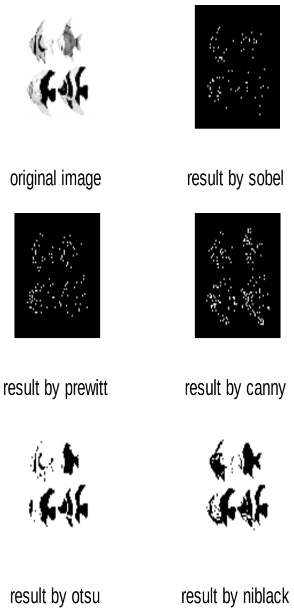

Fig 6 Results of three edge detectors and two thresholding method

Table 1
MSE and **PSNR** values after implementing different edge detection and thresholding methods on different images

Name Of Image	Name of Detection Method	Mean Square Error(MSE)	Peak Signal-to-Noise Ratio (PSNR)
hand.jpg	Sobel edge detection	0.1257	57.1381
hand.jpg	Prewitt edge detection	0.1258	57.1345
hand.jpg	Canny edge detection	0.1201	57.3350
hand.jpg	Otsu’s Method	0.0273	63.7767
hand.jpg	Niblack’s Method(k=.2)	0.0344	62.7700
spine.jpg	Sobel edge detection	0.2081	54.9475
spine.jpg	Prewitt edge detection	0.2084	54.9418
spine.jpg	Canny edge detection	0.2032	55.0522
spine.jpg	Otsu’s Method	0.0396	62.1520
spine.jpg	Niblack’s Method(k=.2)	0.0435	61.7506
text.jpg	Sobel edge detection	0.5815	50.4853
text.jpg	Prewitt edge detection	0.5814	50.4862
text.jpg	Canny edge detection	0.5712	50.5629
text.jpg	Otsu’s Method	0.0460	61.5038
text.jpg	Niblack’s Method(k=-.2)	0.0471	61.3998
lena.jpg	Sobel edge detection	0.4555	51.5455
lena.jpg	Prewitt edge detection	0.4556	51.5452
lena.jpg	Canny edge detection	0.4560	51.5416
lena.jpg	Otsu’s Method	0.0679	59.8130
lena.jpg	Niblack’s Method(k=-.2)	0.0695	59.7100
edge.jpg	Sobel edge detection	0.5027	51.1179
edge.jpg	Prewitt edge detection	0.5023	51.1209
edge.jpg	Canny edge detection	0.5069	51.0814
edge.jpg	Otsu’s Method	0.0760	59.3249
edge.jpg	Niblack’s Method(k=-.2)	0.0661	59.9279
fish.jpg	Sobel edge detection	0.8535	48.8190
fish.jpg	Prewitt edge detection	0.8535	48.8188
fish.jpg	Canny edge detection	0.8368	48.9048
fish.jpg	Otsu’s Method	0.0112	67.6278
fish.jpg	Niblack’s Method(k=-.2)	0.0303	63.3126

VI. Conclusion

In this paper results of different edge detectors and thresholding techniques are compared by using different medical, sharp, smooth and synthetic images. Comparative analysis is done on the basis of visual inspection and quantitative parameters such as mean square error and Peak Signal-to-Noise Ratio values. It has been concluded that results produced by different edge detection methods are different depending upon one's requirement. The operators Sobel and Prewitt provide low quality edge maps relative to the others. Canny produces higher detection rate as compared to sobel and prewitt operators and detects true weak edges because it is not susceptible to noise interference.Otsu, Canny and Niblack produces better results but Otsu is more suitable for images whose objects are distinguishable from their background. It has been found that Otsu's method is much more effective than canny in natural images as well as in medical images as it chooses the threshold to minimize the infraclass variance of the black and white pixels. Niblack method provides good results over text images which are quite similar to the results produced by Otsu's method. Performance parameters in Table 1 also show that Otsu and Niblack's thresholding method produces less mean square and more Peak Signal-to-Noise Ratio. So it has been concluded that Otsu and Niblack are best thresholding methods.

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