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QUALITATIVE ANALYSIS OF VARIOUS EDGE DETECTION TECHNIQUES APPLIED ON CERVICAL HERNIATED SPINE IMAGES

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Abstract

Medical imaging plays a necessary role within the health care enterprise both from the value and patient care perspective. The most common Medical Imaging Systems include Computer Tomography, Magnetic Resonance Imaging, Magnetic Resonance Angiography and Mammography etc. In this paper, various edge detection techniques can be applied on cervical herniated spine images using MRI systems. Its work without using ionizing radiation, have specific uses in the diagnosis of disease. This paper is aimed to compare many edge detection techniques like Sobel, Prewitt, Roberts, Canny, LOG and Zero crossings etc and proposing the best suitable method of edge detection for medical imaging systems. The comparative analysis of medical image edge detection is based on the image quality metrics parameters such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) using MATLAB software. The objective of the paper is to do the edge detection using MRI images and also find the quality measurements to various edge detection operators.

Keywords:

Medical Imaging Systems, Cervical Herniated Spine Images, Edge Detection, Image Quality Metrics

1. INTRODUCTION

Detecting and Edge detection is an essential technology in medical, computer vision and machine vision. It is the first step in recovering information from images. Edges are basic image features. They carry useful information about object boundaries which can be used for image analysis, identification and for image filtering applications as well. An edge can be defined as a set of uninterrupted pixel positions where a sudden change of intensity values occur. An edge is an image is a notable local change in the image intensity, usually associated with a discontinuity in either the image intensity or the first derivative of the image intensity. Based on discontinuities in the image intensity, there are two categories such as 1) step discontinuities and 2) line discontinuities. In early stages of image processing, identifying any features in an image that are relevant to estimating the structure and properties of the objects in that image was the primary motive [1]. The importance of edge detection is that it can help in predicting and comparing the bone density of herniated images before and after the edge detection operation.

The steps in edge detection

- **Filtering**: The purpose of filtering is to upgrade the performance of edge detector with reference to noise. Doing more filtering, the result of noise will be reduced and become heavy loss in edge strength.
- **Enhancement**: Highlight the pixels having significant change in local intensity.
- **Detection**: Find edges by means of thresholding technique.
- **Localization:** Pinpoint the edge accurately, evaluate edge orientation.

In this paper, Human Cervical herniated images are taken for edge detection. The cervical spine is consists of seven vertebrae which articulate with each other to form a strong pillar for the support of the head. Of the seven vertebrae, the atlas (C1), axis (C2) and vertebra prominens (C7) are considered atypical vertebrae while C3 through C6 (typical) vertebrae present with similar characteristics. The atlas connects to the occipital bone above to support the base of the skull. This connection is the atlas-occipital joint [2]. The Magnetic Resonance Imaging (MRI) is a medical imaging technique using radio waves and magnetic fields to create detailed cross-sectional images of internal organs and structures within the body. It is widely used in patient analysis and medical diagnosis. MRI scans the soft tissues of the neck and cervical spine. The MRI scan uses the strength and vitality from strong magnets to create images of the part of the spine that runs along the neck area.

This paper mainly focused on herniated cervical spine images. Cervical discs are the cushions between the vertebrae in the upper back and neck. The herniated disc means a disc in the spine is compressed and there is a leakage of inner disc fluid called Cerebrospinal Fluid (CBF) into the spinal canal. The cervical herniated disc is caused by excessive stress being placed on the disc, whether as a result of heavy lifting or other damaging motions. It is usually seen in 30 to 50 year olds.

Rest of the paper organized as follows: section 2 discuss about the related work. Section 3 deals with proposed comparison strategy for edge detection. Section 4 shows the experimental results and section 5 deals with conclusion.

2. RELATED WORK

The principle of edge detection is thus based on the study of the derivative of the intensity function from the image: the local extrema of the function gradient intensity and the zero crossings of the Laplacian [3]. Edge detection is a type of image segmentation techniques which determines the presence of an edge or line in an image and outlines them in an appropriate way [4]. Generally an edge is defined as the boundary pixels that connect two separate regions with changing image amplitude attributes such as different constant luminance and tri stimulus values in an image. Edge detection is known as straight lines or curves in the image plane across which there is a significant change in image brightness [5]. Based on variation of intensities, edge detectors can be divided into five major criteria: a) step edge detectors, b) line edge detectors, c) junction edge detectors, d) corner detectors, and e) roof edge detectors [6] [7]. Following are some literature surveys based on edge detection techniques.

Veeralakshmi et al. [8] proposed an edge detection technique for detecting the correct border of objects in a picture. It can detect the boundaries of object using the information from intensity gradient using the vector image replica and feel gradient using the edge map model.

Julian et al. [9] presented a method for vessel segmentation and track in ultrasound images using Kalman filters. This method is used to determine vessel contours and ellipse parameters using an extensive Kalman filter with an indirect model. A temporal Kalman filter is used for tracking the vessel center over some frames, using place size from a handheld sensitized ultrasound probe.

Abubakar [10] presents this paper on Global thresholding segmentation on noisy images. With the help of this techniques images corrupted with noise such as salt and pepper and Gaussian firstly converted into grayscale and finally objects of these images are successfully removed from the background.

Padmapriya et al. [11] proposed a method to sense boundary in check-up image using size, direction, edge map and density of the edges bounded to the article and to crop the detect object and expand the image. The blur end product of the enlarged image is removed and a high decision image is bent from the low resolution image.

Singh and Chadha [12] suggested a novel approach to divide the image into multiple pieces to get more efficient vision of the image. They adopt the segmentation based on edge detection of the image present in background and foreground. After having the edge detection, dilation is applied over the image and correctness is achieved for all type of images but stability is not achieved in case of .png format of images.

In general, edge detection technique based on segmentation, can be divided into following categories, are depicted in Fig.1 as shown below.

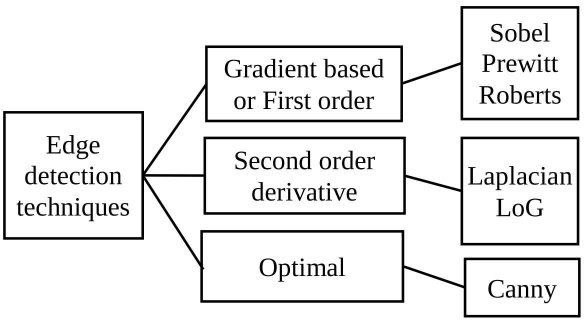

Fig.1. Edge based segmentation techniques

2.1 GRADIENT BASED EDGE DETECTION

The gradient of the image (Δf) can be represented as

$$\Delta f = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (1)$$

where, $\frac{\partial f}{\partial x}$ is known as the gradient in x direction and $\frac{\partial f}{\partial y}$ is known as gradient in y direction. For an image function, $f(x,y)$, the gradient magnitude, $g(x,y)$ and the gradient direction, $\theta(x,y)$ are computed as

$$g(x,y) \cong \frac{1}{\Delta x^2 + \Delta y^2} \quad (2)$$

and

$$\theta(x,y) \cong a\tan\left(\frac{\Delta x}{\Delta y}\right) \quad (3)$$

where,

$$\Delta x = f(x+n,y) - f(x-n,y)$$

$$\Delta y = f(x,y+n) - f(x,y-n)$$

and n is a small integer usually 1.

Various edge detection techniques are as follows:

2.1.1 Sobel Edge Operator:

The Sobel edge detection operator is the most popular edge detection operator until the development of edge detection techniques with a theoretical basis. [13]. In Sobel edge detection, the image is processed in the x and y directions separately first and then combined together to form a new image, which represents the sum of the x and y edges of the image. The x and y masks are first convolved with the image t compute the values of Δx and Δy. The magnitude and angle of the edges are computed from these values and stored as two separate image frames as shown below:

$$\Delta x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (4)$$

and

$$\Delta y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (5)$$

The Sobel operator is used to detect the edge strength and edge direction in the image. All the edges with lower value than threshold are ignored and if threshold is not given then edge selects the value automatically. A common issue with sobel edge detector is the fact that it tends to be a lot of noise in the final processed image.

2.1.2 Prewitt Operator:

It is a discrete differentiation operator. It computes the approximation of gradient intensity function [14]. Prewitt operator provides two masks, one for detecting edges in horizontal direction and another for in vertical direction. The mask of Δy can be derived from Δx by simply rotating 90° is as shown below:

$$\Delta x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \quad (6)$$

$$\Delta y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \quad (7)$$

The Prewitt operator is a gradient based edge detection operator and used to calculate the orientation and magnitude of an edge and estimate in the 3×3 neighborhood for 8 directions.

2.1.3 Roberts Operator:

The convolution mask of Δx and Δy with rotation angle of 90° is defined as

$$\Delta x = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \tag{8}$$

$$\Delta y = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \tag{9}$$

The Roberts edge detector is a gradient based edge detection operator and provide a 2D spatial gradient measurement of an image and has 2×2 convolution mask. The Roberts edge detection is fast since the filter is small but it is also subject to interference by noise.

2.1.4 Zero Crossing Method:

Based on edge detection, the positioning of the edge point is located at the zero crossing of the first derivative of the filter. For a given threshold, the error of localization is a function of the slope of the first derivative in the neighborhood of zero. The Zero Crossing detector looks for places in the Laplacian of an image where the value of the Laplacian passes through zero. It is largely governed by the standard deviation of the Gaussian used in the LoG filter. These results are strongly influenced by the side of the Gaussian used for the smoothing stage of this operator.

2.1.5 The Laplacian of Gaussian:

It is also called as Marr and Hildreth operator who combined Gaussian filtering with the Laplacian. It may detect edges as well as noise. It is useful for detecting edges that appear at various image scales r degrees of image focus. The exact values of sizes of two kernels that are used to approximate the Laplacian Of Gaussian will determine the scale of the difference image which may appear blurry as a result. It finds the correct place of edges and testing wider area around the pixel [15]. The Laplacian of an image highlights regions of rapid intensity change. It is common for a single image to contain edges having widely different sharpness and scales from blurry and gradual to crisp and abrupt.

2.1.6 Canny Operator:

The Canny operator works in a multistage process. The effect of this canny operator is determined by three parameters. First one is the width of the Gaussian kernel used in the smoothing phase. Second and third one are the upper and lower thresholds used by the tracker. The Canny edge detector contains the steps as follows:

Step 1: Preprocessing: Applying the Gaussian with smoothing on images, to reduce noise.

Step 2: Calculating gradients: The upper threshold and the lower threshold are the key parameters and the former one is used to mark edges that are definitely edges and the latter one is used to find faint pixels that are actually a part of an edge.

The magnitude of gradient is,

$$m = \sqrt{G_x^2 + G_y^2} \tag{10}$$

The direction of gradient is,

$$\theta = \arctan\left(\frac{G_x}{G_y}\right) \tag{11}$$

where, G_y and G_x are the x and y derivatives at the point being considered.

Step 3: Non maximal suppression: If a pixel is not a maximum, then it is suppressed. So we can do iteration over all the pixels.

Step 4: Thresholding with hysteresis

a. If the current pixel is not an edge, check next one.

b. If it is an edge, check two pixels in the direction of edge.

c. Have the direction in the same bin as the central pixel.

i. Check Gradient magnitude is greater than Lower threshold.

ii. After comparing with neighbors, mark these pixels as an edge pixel.

iii. Continue the process until there are no changes in the image.

iv. If the image stops changing, then exit.

The main advantage of Canny edge detector is using the probability for finding error rate and it improves signal to noise ratio.

3. PROPOSED COMPARISON STRATEGY FOR VARIOUS EDGE DETECTORS

The image quality is the characteristic of an image that measures the perceived image degradation. Measurement of image quality is very crucial to many image processing applications. Image quality can degrade due to distortions during image acquisition and processing. Various distortions like noise, blurring and compression artifacts are available in images. Efforts have been made to create objective measures of quality. In this paper, we analyze two well-known objective image quality metrics, the Peak Signal to Noise Ratio (PSNR) as well as Mean Square Error (MSE) are used to find the similarities and dissimilarities between various edge detection operators.

3.1 MEAN SQUARE ERROR (MSE)

MSE providing the quantitative score that describes the degree of similarity or dissimilarity, the level of error/distortion between them. It incorporates degradation function and statistical characteristics of noise in the edge detected image. It is used to compare the image edge detection quality. It specifies the average distance of the pixels throughout the original ground truth image with edge detected image. The mean square error between two images $f(x,y)$ and $f'(x,y)$ can be expresses as

$$MSE = \frac{1}{XY}\sum_{i=0}^{x-1}\sum_{j=0}^{y-1}\left[f'(i,j) - f(i,j)\right]^2 \tag{12}$$

3.2 PEAK SIGNAL NOISE RATIO

PSNR is one of the error metrics used in image compression. Based on Image compression, PSNR is used to measure the quality of reconstruction of Lossy and Lossless compression of image. PSNR relates the magnitude of the noise to the peak value in the image. It is defined as decibels as follows:

$$PSNR = 10\log_{10}\left(\frac{p}{RMS}\right)dB \quad (13)$$

where p is the peak value of the signal i.e. 255 and RMS is the root mean square delta between the original image and the output image. Higher PSNR means more noise removed.

3.3 STRUCTURAL SIMILARITY INDEX METRIC

SSIM method is used for estimating the perceived quality of digital television and various kinds of digital images and videos. It is used for measuring the similarity between two images. SSIM method is clearly more involved than MSE method, but the SSIM attempts to model the perceived change in the structural information of the image whereas the MSE is actually estimating the perceived errors.

SSIM is based on three comparison measures as luminance (l), contrast (c) and structure (s) between the images as X_1 and X_2 as expressed as

$$SSIM = function\left(l\left(X_1, X_2\right), c\left(X_1, X_2\right), s\left(X_1, X_2\right)\right) \quad (14)$$

The main limitation of SSIM is, more complicated to compute and also it is inability to measure highly blurred images.

4. EXPERIMENTAL RESULTS

Various edge detection techniques are experimented on herniated cervical MRI images. We have acquired 12 medical images and remove noise by using median filter. Different edge detection operators such as Sobel, Prewitt, Roberts, Zero Crossing, LoG and Canny images are applied using Matlab software as shown in Fig.2.

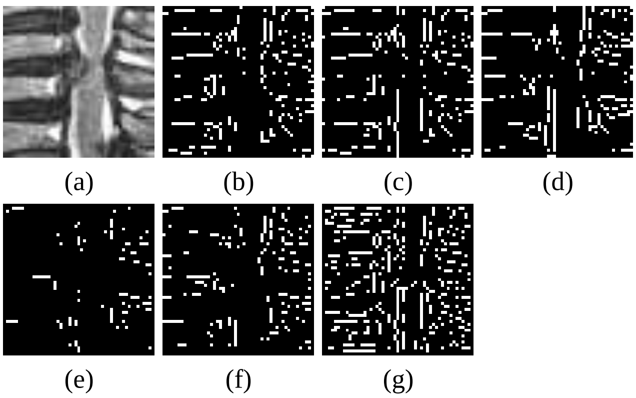

Fig.2. (a) Original Herniated Image (b) Sobel Image (c) Prewitt Image (d) Roberts Image (e) Zero Crossing Image (f) Log Image (g) Canny Image

From the Fig.2, Given MRI original Herniated image, the corresponding Sobel, Prewitt, Roberts, Zero Crossing, LoG and Canny edge detector operators are shown. Among all edge detectors, the Zero Crossing method of image has less amount of visible edges. Prewitt edge detector has less invisible lines as compared to Sobel operator. Roberts image has more visible lines as compared to LoG image. More visible lines are only attained in Canny method of edge detection. Canny image alone has more clarity than other edge detected images. Because canny method used multi-stage algorithm, to detect a wide range of edges in images. It is less sensitive to the noise as compared to other edge detectors. The application of this detection is control the amount of detail, which appears in the edge images and suppress noise also.

The next step is finding the Image Quality Metrics applied on each cervical herniated image. In noise level, two metric standards are universally followed, Peak Signal Noise Ratio (PSNR) and Mean Squared Error (MSE). Based on quality metrics, such as Mean Square Error (MSE) and Peak Signal Noise Ratio (PSNR), the similarities and dissimilarities between various edge detection images are tabulated and shown in the following Table.1 and Table.2.

Table.1. MSE Comparison values of Herniated Image

	Sobel	**Prewitt**	**Roberts**	**ZC**	**LoG**	**Canny**
Sobel	0	0.0007	0.0003	0.0081	0.0124	0.0113
Prewitt	0.0007	0	0.0004	0.0074	0.0117	0.0120
Roberts	0.0003	0.0004	0	0.0078	0.0121	0.0116
ZC	0.0081	0.0074	0.0078	0	0.0043	0.0194
LoG	0.0124	0.0117	0.0121	0.0043	0	0.0237
Canny	0.0113	0.0120	0.0116	0.0194	0.0237	0

Table.2. PSNR comparison values of Herniated Image

	Sobel	**Prewitt**	**Roberts**	**ZC**	**LoG**	**Canny**
Sobel	0	0.0111	0.0038	0.1387	0.2138	0.1872
Prewitt	0.0111	0	0.0073	0.1276	0.2017	0.1983
Roberts	0.0038	0.0073	0	0.1349	0.2100	0.1910
ZC	0.1387	0.1276	0.1349	0	0.0751	0.3259
LoG	0.2138	0.2027	0.2100	0.0751	0	0.4010
Canny	0.1872	0.1983	0.1910	0.3259	0.4010	0

From Table.1 and Table.2, it can be observed that Canny Edge Detection has the large difference in the quality metrics measurement as compared to all other edge detection operators. Based on Table.1 and Table.2, the higher values of dissimilarities can be considered as the best edge detectors. So from the Table.1 and Table.2, Canny has the high dissimilarities as compared to all other edge detectors.

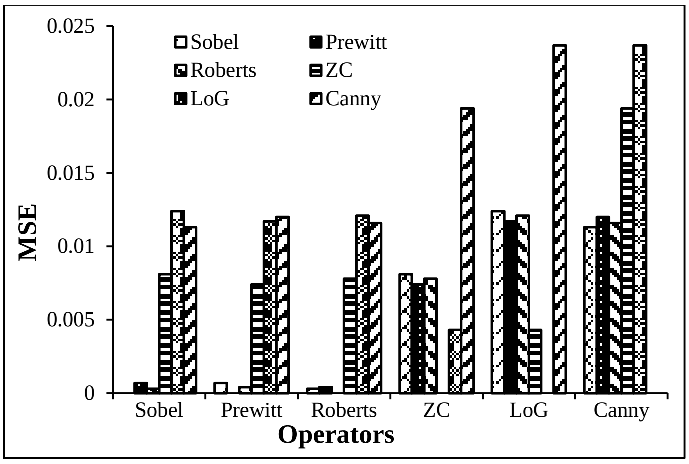

Fig.3. MSE graph of Herniated Image

In Fig.3 and Fig.4, the performance graph of Mean Square Error and Peak Signal Noise Ratio of cervical herniated image are measured. MSE represents the cumulative squared error between the compressed image and the original image, whereas the PSNR represents a measure of peak error. The PSNR usually represents in terms of the decibel (dB) scale. A higher in PSNR value generally indicates that the reconstruction is of higher quality in image compression. But in some cases like edge detection, PSNR should lesser to achieve proper results.

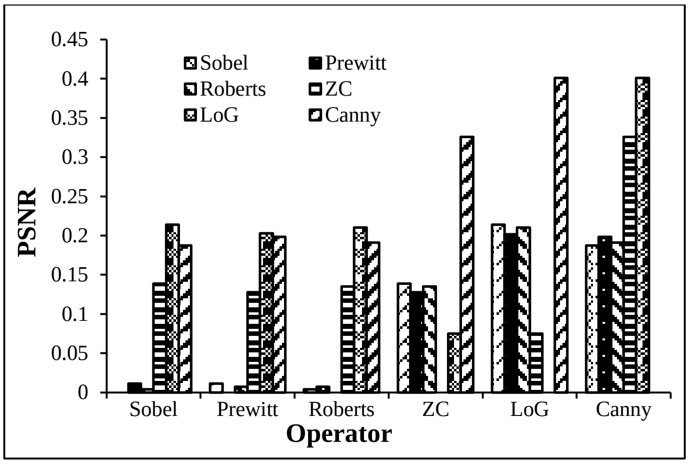

Fig.4. PSNR graph of Herniated Image

From the Fig.3 and Fig.4, the comparative analysis of each edge detector with other edge detector values are compared with the quality metrics of MSE and PSNR. In Table.1, the MSE comparison of Sobel with all edge detectors, Prewitt with all edge detectors and so on. Finally Canny MSE values are compared with all other edge detectors MSE values. In the same way, PSNR values are also compared with each edge detectors. It can be indicated that canny edge detection attains high MSE and low PSNR value as compared to various edge detectors. It has been observed that Canny edge detection provides good and reliable detection of edges as compared to Sobel, Prewit, Roberts, ZC and LoG Edge detection operators.

5. CONCLUSION

This paper discussed six important edge detectors and its image quality metrics performance based on the two metrics, Mean Square Error and Peak Signal to Noise Ratio. Since edge detection is the initial step in object boundary extraction and object recognition, it is important to know the differences between different edge detection operators. By visual appearance of the above results after applying various edge detectors on medical images, one can easily determine the best edge detector for medical imaging applications. After all experiments, it is concluded that Canny edge detection technique is the best among other edge detection techniques. The next stage of performance in image quality is ranked as Prewitt, Sobel, Roberts, LoG and Zero Crossing edge detectors. Based on Medical Images, it is concluded that Canny Edge Detection method is better than all other edge detectors in anyway.

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