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Noise-Resilient Edge Detection Algorithm for Brain MRI Images

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***Abstract* — In this paper we introduce a noise-resilient edge detection algorithm for brain MRI images. Also, an improved edge detection based on Canny edge detection algorithm is proposed. Computer simulations show that the proposed algorithm is resilient to impulsive noise which makes up for the disadvantages of Canny algorithm, and can detect more edges of MRI brain images effectively. Also, the concept of images fusion is utilized for effective edge detection.**

***Keywords*—Noise resilient, Canny operator, edge detection, gradient vector, image fusion ,medical image segmentation**

I. INTRODUCTION

Image edge detection is an effective image processing tool that provides essential image edge information and characteristics. This information is used in wide areas such as image segmentation, image categorization, image registration, image visualization, and pattern recognition. These applications may vary in their outputs but they all share the common need of precise edge information in order to carry out the needed tasks successfully. An edge detector can be defined as a mathematical operator that responds to the spatial change and discontinuities in a gray-level (luminance) of a pixel set in an image [1][7].

Medical images edge detection is an important step towards object recognition of the human organs such as brain soft tissues, and other different organs. It represents an essential pre-processing work in medical image segmentation [4]. It has also been used for other medical applications concerned with the reconstruction of Computed Tomography (CT) scans [5]. Conventionally, after MRI image acquisition takes place, various post processing algorithms are applied to MRI images in order to extract more information. This information can be obtained through edge detection, especially of tissue borders. This process plays a significant rule in recognition of pathological alternations in MRI images [9]. Automatic detection of brain structures is motivated by an ongoing effort to advance knowledge about relationships between anatomy and mental diseases in human brains. Brain images can be used for stroke and tumor evaluation, surgery planning, MRI angiography, or venography studies. Automatic Segmentation of noisy images with complex structures such as magnetic resonance brain images is difficult using general purpose method. The key step of segmentation is to develop an image dependant good edge detection, good localization and a single edge response. Moreover, edge information can be used to feed-in various applications seeking the segmentation of certain objects based on different shapes, size, or edge locations of particular interests. In all edge detection algorithms, the main objective is to locate the edge (intensity transitions) from the scene neither with prior information nor with human interpretation. Some popular algorithms include Sobel, Roberts, Prewitt, Laplace, LOG, and Canny Algorithm [2].

These algorithms can be viewed as high pass filtering algorithms but not designed for high frequency impulsive noise. This would result in detecting noisy edges. In real world applications, medical images contain object boundaries, object shadows and noise. Therefore, they may be difficult to distinguish the original object edges from the noise or trivial geometric features producing false edges.

Canny method has proven to be superior over many of the available edge detection algorithms and thus was chosen mostly for real time implementation and testing. Canny edge detection algorithm was introduced in 1986 [2]. It is considered as the modern "standard" in the sense that the validity of all other algorithms is often checked against it [3]. In Canny algorithm, the Gaussian function is used to smooth the image prior to edge detection. The filtering or smoothing operation actually services two purposes. The first one is the reduction of the effect of Gaussian noise prior to the detection of pixel intensity changes. The second purpose is setting the resolution or scale at which intensity changes are to be detected [3]. These factors contribute effectively towards a precise edge detection method, overcoming the problem of detecting false edges resulted from noise sitting on some pixels.

Canny algorithm has the defect of being vulnerable to noise disturbances and impulsive noise, so there are certain limitations to its application. Also, the traditional Canny operator has a precise edge positioning but quite sensitive to noise and may detect false edges, as well as missing some details of real edges in an image [1]. This issue is of a great importance in noisy images where many false edges resulting from noise are detected. Furthermore, the Canny edge detector cannot detect branching edges as well [8]. Because of the existence of impulsive noise in medical images, traditional Canny algorithm doesn't perform well since it can't eliminate some noises, thus, generating many false edges. It is difficult to design a general edge detection algorithm which performs well in many contexts and captures the requirements of subsequent processing stages. Consequently, over the history of digital image processing, a variety of edge detectors have been devised which differ in their mathematical and algorithmic properties [10].

In this paper, an algorithm for MRI edge-detected brain images in a denoising environment is proposed. Also, an improved Canny edge detection algorithm has been developed for a better edge detection. The paper is organized as follows. The proposed edge detection algorithm concerned with noise resilience, is described in Section 3. The developed Canny operator is described in Section 4. Experimental results are presented and discussed in Section 5. Finally, conclusions are drawn in Section 6.

II. BACKGROUND

Canny operator consists of the main processes as shown in Figure (1). The first order Gaussian function is defined as:

$$G(x,y,\sigma)=\frac{1}{2\pi\sigma^2}e^{\left(\frac{-x^2+y^2}{2\sigma^2}\right)} \qquad (1)$$

The Gaussian smoothing function smoothes out the image to have a noise-free image prior to applying the derivative function. The derivative function is approximated using a 3 x 3 kernel that is applied on the horizontal *(Gx)* and vertical *(Gy)* direction of an image.

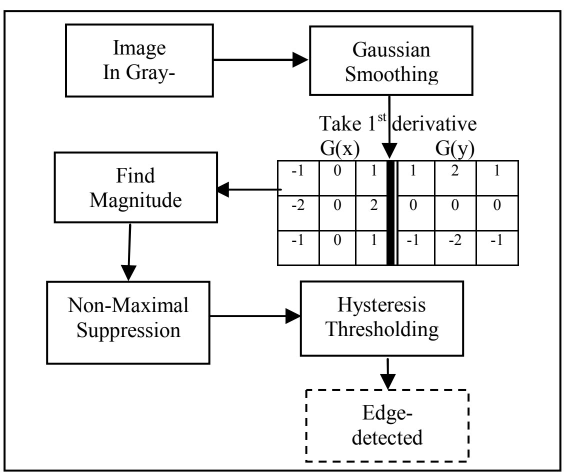


Figure (1). Canny edge detection process

By convolving the previous kernels of *G(x)* and *G(y)* with the Image, the gradient vector $\nabla G=\begin{bmatrix}\partial G/\partial x\\ \partial G/\partial y\end{bmatrix}$ (2)

results. The magnitude and the direction of each pixel of the image can be calculated using:

Magnitude = $\sqrt{(\partial G/\partial x)^2+(\partial G/\partial y)^2}$ (3)

Direction: $\Theta = \arctan\left(\frac{\partial G/\partial y}{\partial G/\partial x}\right)$ (4)

III. IMAGE DENOISING THROUGH DECOMPOSITION

In this part, the Laplacian of Gaussian (LoG) is applied on the MRI image of interest. The Laplacian provides the isotropic measure of the 2^{nd} spatial derivative of the image. It highlights the region of rapid intensity change. The measure of the output of LoG is used to decompose the original image into two images. The first image is the image of interest and contains the original image information that has values greater than or equal their corresponding LoG values. The second image contains all values that are less than their corresponding LoG values. The following figure highlights this concept. The second image is ignored as it contains the major noise impulsive components.

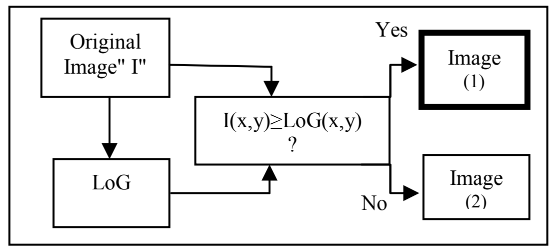


Figure (2): Block diagram of Image decomposition

The next step is to feed the output of the previous algorithm, i.e. image (1) to the improved Canny edge detector highlighted next.

IV. IMPROVED CANNY EDGE DETECTION

Conventional Canny algorithm works as follows:

A. Smooth an image with Gaussian filter.
B. Calculate gradient magnitude and gradient direction.
C. "Non - maximal suppression" to ensure the desired edge with one single pixel width.
D. Determine two threshold values, and then select possible edge points and trace edges.

A. Replacement of Gaussian smoothing kernel

The first part is to replace the Gaussian smoothing kernel with one of the following kernels for enhancing the image edges in both directions.

$$\begin{bmatrix}-1&-1&-1\\-1&\alpha&-1\\-1&-1&-1\end{bmatrix},\begin{bmatrix}0&0&-1&0&0\\0&-1&-2&-1&0\\-1&-2&\alpha&-2&-1\\0&-1&-2&-1&0\\0&0&-1&0&0\end{bmatrix} \qquad (5)$$

where α = 2, 4, or 8. Extensive simulations results showed that α = 2 has the best performance.

B. Modification of the gradient magnitude of Canny operator

It was shown previously that the gradient operator of the horizontal and vertical directions can be computed as $\partial G / \partial x$ and $\partial G / \partial y$ respectively. The presented algorithm joins together gradient magnitude and direction:

$$\text{Magnitude } (x,y,\theta) = \text{Max } \left(\cos\theta \frac{\partial G}{\partial x}, \sin\theta \frac{\partial G}{\partial y} \right) \quad (6)$$

C. Modification of gradient kernel

The Canny method gradient magnitude and direction are calculated by pixels within a 2-by-2 neighborhood and sensitive to detect false edges. One solution is to calculate the gradient magnitude and direction by using pixels within an M-by-N neighborhood. In [6], a generalized set of kernels for derivative approximation was introduced. It can be used effectively for edge detection, line detection, and consequently for feature extraction. Kernel sizes could be of 5x11, 3x9 or 5x7.

$$G(x) = \begin{bmatrix} 1 & \sqrt{2} & 2 & 0 & -2 & -\sqrt{2} & -1 \\ \sqrt{2} & 2 & 2\sqrt{2} & 0 & -2\sqrt{2} & -2 & -\sqrt{2} \\ 2 & 2\sqrt{2} & 4 & 0 & -4 & -2\sqrt{2} & -2 \\ \sqrt{2} & 2 & 2\sqrt{2} & 0 & -2\sqrt{2} & -2 & -\sqrt{2} \\ 1 & \sqrt{2} & 2 & 0 & -2 & -\sqrt{2} & -1 \end{bmatrix}, G(y) = \begin{bmatrix} 1 & \sqrt{2} & 2 & \sqrt{2} & 1 \\ \sqrt{2} & 2 & 2\sqrt{2} & 2 & \sqrt{2} \\ 2 & 2\sqrt{2} & 4 & 2\sqrt{2} & 2 \\ 0 & 0 & 0 & 0 & 0 \\ -2 & -2\sqrt{2} & -4 & -2\sqrt{2} & -2 \\ -\sqrt{2} & -2 & -2\sqrt{2} & -2 & -\sqrt{2} \\ -1 & -\sqrt{2} & -2 & -\sqrt{2} & -1 \end{bmatrix} \quad (7)$$

D. Fusion of edge images

Conventional Canny algorithm uses a method of non-maximum suppression (NMS) to process the smoothed image and make sure each edge is of one-pixel width. In this method, a fusion of two edge detection techniques is proposed. The first edge-detected image contains the modified kernel set in (7). The second edge-detected image contains the same kernel set mentioned previously in addition to using the modified gradient magnitude in (6). The fusion of the two edges would guarantee the existence of all edges that one image may miss over the other one. Figure (3), shows the proposed fusion concept.

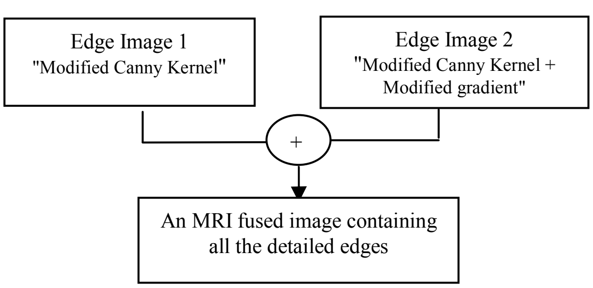
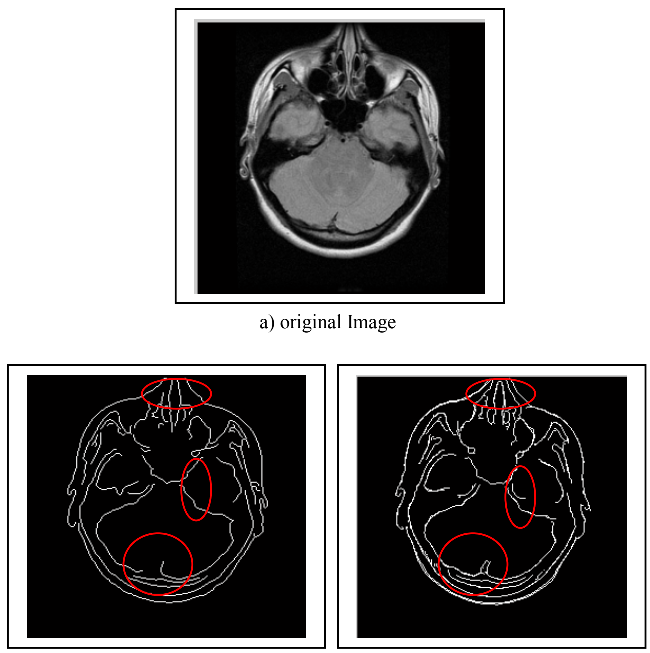


Figure (3). A block diagram showing the fusion of two edges

V. SIMULATION RESULTS AND COMPARISON

In this section, various brain MRI test images are edge-detected using the original Canny method, and compared with those deploying the new proposed algorithm. MATLAB environment is used to simulate the execution of both algorithms. In Figure (4), the original MRI image is edge detected using the proposed algorithm and compared with the original Canny output in noise-free environment. It is noted that the proposed algorithm succeeds in finding more necessary edge details when compared with the original Canny.

One might note that there are little curves that may not be fully connected. The reason for this goes to the performance of the LoG. The Laplacian filter here makes it less sensitive to the edge orientation at corners and curves where intensity level varies rapidly. Also, because this is an image dependent procedure in terms of choosing the size of the applied kernel, some little lines may not be fully connected.



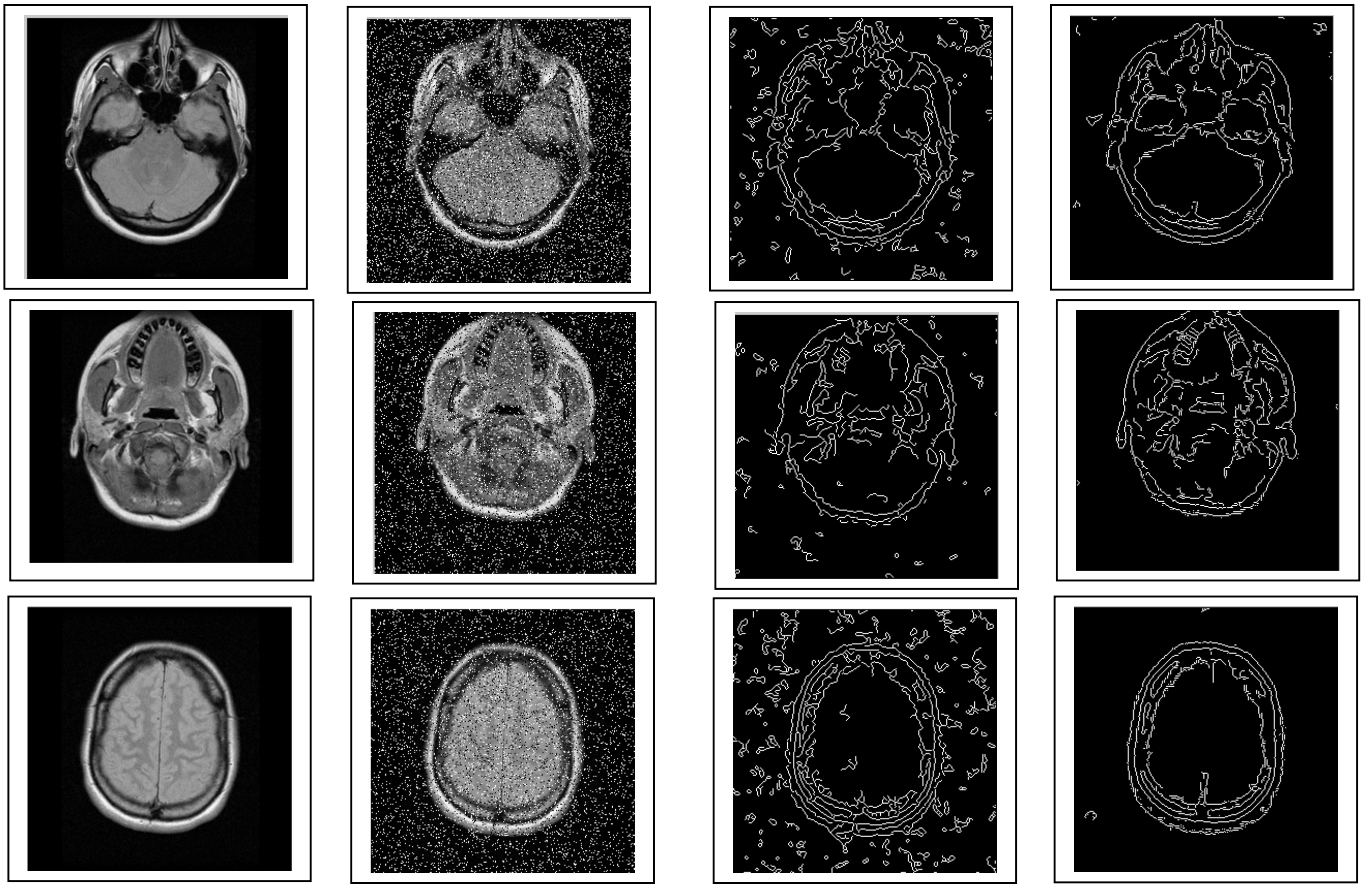
a) original Image

b)Original Canny

c)Algorithm output

Figure (4). Edge detection comparison of a brain MRI image

In Figure (5), impulsive noise is added to different brain MRI images. Then, Each image is edge detected using the Canny method and the proposed algorithm for comparison.



a)Original Image b) Noisy Image c) Original Canny output d) Algorithm output

Figure (5). Edge-detected MRI images comparison

It is noted that the introduced algorithm provides almost a noise-free edge detection. It overcomes the problem of detecting noisy false edges in MRI brain scans. This method can also be generalized to be superior to the original Canny edge detection in terms of detecting more sensitve images details as shown previously in figure (4).

VI. CONCLUSION

In this paper, a noise- resilient edge detection algorithm for medical brain MRI images is introduced. Also, an improved Canny edge detection algorithm is proposed, and utilized in the fusion of the detected edges. MRI brain scans are selected to test the proposed algorithms. Computer simulations show that the proposed algorithm is noise-resilient and able to edge-detect brain MRI images effectively in an impulsive noise environument. Also, it makes up for the disadvantages of Canny algorithm, and can detect more edges of MRI brain images effectively.

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