Performance evaluation of the various edge detectors and filters for the noisy IR images

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Abstract:
Edge detection is an important process of image processing and it is the foundation of pattern recognition, which will affect the later processes. Especially in a noisy image, the edge detection is more important because noise is a common phenomenon in an image. This paper deeply studies the edge detection methods for noisy IR images and also studies the performance of the filters involved in removing the noise. Four basic edge detection operators such as Sobel, Prewitt, Log and Canny were selected and a comparison is done to check the quality of the edge detectors with noisy IR images. The study shows that the Sobel edge detector is best in detecting the edges when compared to other edge detectors. Then, the filters such as Median, Lee and Kuan were used to remove the noise in IR image. After applying all the filters the result shows that Median filter works good among the three filters. The quality of the edge detectors and the filter is calculated using the parameters PSNR and RMSE.

Keywords: Edge Detection, Image Processing, IR Image, Peak signal to noise ratio (PSNR), Root mean square error (RMSE).

I. INTRODUCTION

The goal of edge detection is to convert a 2D image into a set of curves. The salient features are expected to be the boundaries of objects that tend to produce sudden changes in the image intensity. Edges define the boundaries between regions in an image, which helps with segmentation and object recognition. They can show where shadows fall in an image or any other distinct change in the intensity of an image. The quality of edge detection is highly dependent on lighting conditions, the presence of objects of similar intensities, density of edges in the scene.

Since different edge detectors work better under different conditions, the objective of this paper is to identify the suitable edge detector for the IR images with the noise present in it. Moreover, the aim is to find the good edge detector for the filtered images and the respective filter used for the identification of the same. The reason for choosing IR image is that quality of the IR images differs from the normal images. The edge detection operators such as the Sobel, Prewitt, Log and Canny are commonly used in the process of the edge detection. The noise taken for the study is Salt and Pepper noise a type of Impulsive noise, where the noise value may be either the minimum or maximum of the dynamic gray scale range of the image.

The study begins by taking IR images, and then to add salt and pepper noise with probability 0.1. Edge detector operators are applied to all the noisy IR images. Then, the PSNR value is calculated between the original image and the edge detected noisy images. The values show that the Sobel edge detection operator is best for detecting the edge for the noisy images. After applying all the filters to the noisy IR images, the noise is removed from the image. Then followed by that Sobel edge detection operator is applied to all the filtered images. The PSNR value is calculated between the original image and the filtered edge-detected images. The values are used to evaluate which filter gives the better performance. The results show that after applying all the three filters, Median filter performs well with the Sobel operator. Larger the PSNR value the performance is good and smaller the RMSE value the error rate is low. The organization of this paper is as follows: Section 2 gives the general classification of the edge detection. Section 3 explains the advantages and disadvantages of the edge detectors and the Section 4 shows the method to evaluate the performance of edge detectors, Section 5 presents the results and finding. Finally the section 6 concludes the paper.

II. GENERAL CLASSIFICATION OF THE EDGE DETECTOR

A large number of edge detection techniques have been proposed in the literature. The common approach is to apply the first (or second) derivative to the smoothed image and then find the local maximal (or zero-crossings)[1]. The general classification of the edge detection is based on the behavioral study of the edges [2]. Edge detection can be classified as follows:

- Gradient Edge Detectors (first derivative or classical)
✓ Laplacian Method (second derivative)
   \[ G = \frac{(c-g-a+i)}{2} + f - d, \frac{(c-g+a-i)}{2} + b - h \]

✓ Gaussian Edge detectors.

2.1 Gradient Edge Detectors:
Gradient Edge Detectors measure the gradient of the image along two orthogonal axes. It is the best for abrupt discontinuities [3]. The edge detectors contain classical operators and uses first directional derivative operation. It includes algorithms such as Sobel (1970), Prewitt (1970), and Robert’s operators.

a) Sobel Operator:
The Sobel operator is used in image processing, particularly within edge detection algorithms. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. Steps [4] involved in Sobel edge detector are as follows.

Step 1: Convolution with gradient (Sobel) filter
Step 2: Magnitude of gradient.
Step 3: Thresholding.

The standard Sobel operators, for a 3×3 neighborhood, each simple central gradient estimates the vector sum of a pair of orthogonal vectors [5]. Each orthogonal vector is a directional derivative estimate multiplied by a unit vector specifying the derivative’s direction. Thus for a point on Cartesian grid and its eight neighbors having density values as shown as follows:

\[
\begin{matrix}
a & b & c \\
e & d & f \\
g & h & i \\
\end{matrix}
\]

Fig 1: Cartesian grid and its eight neighbors

The directional derivative estimate vector \( G \) is defined as density difference / distance to neighbor. This vector is determined such that the unit vector will give the direction of \( G \) to the approximate neighbor.

\[
G = \frac{(c-g)}{R} \cdot [1,1] + \frac{(a-i)}{R} \cdot [-1,1] + (b-h) \cdot [0,1] + (f-d) \cdot [1,0]
\]

Where, \( R = 2 \).

Fig 2: Weighting functions for x and y

Prewitt’s operator:
The basic idea behind edge detection is to find places in an image where the intensity changes rapidly. Based on this idea, an edge detector may either be based on the technique of locating the places where the first derivative of the intensity is greater in magnitude than a specified threshold or it may be based on the criterion to find places where the second derivative of the intensity has a zero crossing [6].

The prewitt operator is limited to 8 possible orientations, however experience shows that most direct orientation estimates are not much more accurate. This gradient-based edge detector is estimated in the 3x3 neighborhood for eight directions [7].

All the eight convolution masks are calculated. For each pixel the local edge gradient magnitude is estimated with the maximum response of all 8 kernels at this pixel location:

\[ |G| = \max (|G_i|; i=1 \text{ to } n) \]

Where \( G_i \) is the response of the kernel \( i \) at the particular pixel position and \( n \) is the number of convolution kernels. The local edge orientation is estimated with the orientation of the kernel that yields the maximum response. Various kernels can be used for this operation [8] are given below.

-1  1  1
-1  2  2
-1  1  1

Fig 3: Prewitt edge detecting templates sensitive to edges at 0\(^{\circ}\) and 45\(^{\circ}\).

-1  1  1
-1  2  2
-1  1  1

Fig 4: Operation of Prewitt- Edge Detection Operator

In theory, the operator consists of a pair of 2×2 convolution kernels as shown in below Figure One kernel is simply the other rotated by 90\(^{\circ}\). This is very similar to the Sobel operator. These kernels are designed to respond maximally to edges running at 45\(^{\circ}\) to the pixel grid, one kernel for each of the two perpendicular orientations are given as

\[
\begin{matrix}
1 & 1 & 1 \\
0 & 0 & 0 \\
-1 & -1 & -1 \\
\end{matrix}
\]

\[
\begin{matrix}
1 & 0 & 1 \\
0 & 0 & 2 \\
-1 & 0 & 1 \\
\end{matrix}
\]
The kernels can be applied separately to the input image, to produce separate measurements of the gradient component in each orientation (call these $G_x$ and $G_y$). These can then be combined together to find the absolute magnitude of the gradient at each point and the orientation of that gradient. The gradient magnitude is given by:

$$|G| = \sqrt{G_x^2 + G_y^2}$$

Although typically, an approximate magnitude is computed using:

$$|G| = |G_x| + |G_y|$$

This co-efficient is much faster to compute. Often, the absolute magnitude is the only output the user sees the two components of the gradient are conveniently computed and added in a single pass over the input image using the pseudo-convolution operator. Using this kernel the approximate magnitude is given by:

$$|G| = |P1-P4| + |P3-P4|$$

c) Roberts cross edge detector:

The Roberts Cross operator performs a simple, quick to compute, 2-D spatial gradient measurement on an image. It highlights regions of high spatial frequency, which often correspond to edges. In its most common usage, the input to the operator is a grayscale image, as is the output. Pixel values at each point in the output represent the estimated absolute magnitude of the spatial gradient of the input image at that point.

Working

In theory, the operator consists of a pair of 2x2 convolution kernels as shown in the below figure. One kernel is obtained by simply rotating another by 90°. This is very similar to the Sobel operator. These kernels are designed to respond maximally to edges running at 45° to the pixel grid, one kernel for each of the two perpendicular orientations are shown as

$$\begin{pmatrix} 0 & +1 \\ -1 & 0 \end{pmatrix} \quad \begin{pmatrix} +1 & 0 \\ 0 & -1 \end{pmatrix}$$

Fig 6: $G_x$ $G_y$

The kernels can be applied separately to the input image, to produce separate measurements of the gradient component in each orientation. The gradient magnitude is given by:

$$|G| = \sqrt{G_x^2 + G_y^2}$$

Although typically, an approximate magnitude is computed using:

$$|G| = |G_x| + |G_y|$$

2.2) Laplacian of Gaussian (LoG):

As Laplacian operator may detect edges as well as noise (isolated, out-of-range), it may be desirable to smooth the image first by convolution with a Gaussian kernel. This algorithm is not used frequently in machine vision. Steps involved in LoG method are as follows [9].

Step 1: Smoothing is done with Gaussian Filter.
Step 2: Detection is based on zero-crossings.
Step 3: Edge location

The Laplacian method searches for zero crossings in the second derivative of the images to find the edges. The Laplacian of a 2-D function $f(x, y)$ is a second-order derivative defined as,

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

The Laplacian is a 2-D isotropic measure of the 2nd spatial derivative of an image. The Laplacian of an image highlights regions of rapid intensity change and is therefore often used for edge detection. The Laplacian is usually combined with smoothing as a precursor to finding edges via zero-crossings. The 2-D Gaussian function

$$h(x, y) = -e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Where $\sigma$ is the standard deviation, blurs the image with the degree of blurring being determined by the value of $\sigma$. The Laplacian of $h$ is

$$\nabla^2 h(x, y) = -\left[\frac{x^2+y^2-2\sigma^2}{\sigma^4}\right]e^{-\frac{x^2+y^2}{2\sigma^2}}.$$
III. ADVANTAGES AND DISADVANTAGES OF EDGE DETECTORS

As edge detection is a fundamental step, it is necessary to point out the true edges to get the best results from the matching process. First present some advantages and disadvantages of edge detection operators [12] are tabulated in Table.1

<table>
<thead>
<tr>
<th>Methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sobel, Prewitt</td>
<td>Detection of edges and their Orientations</td>
<td>Inaccurate</td>
</tr>
<tr>
<td>Laplacian of Guassian (LoG)</td>
<td>Finding the Correct places of the Edges</td>
<td>Corners and curves where the gray Level intensity function varies</td>
</tr>
<tr>
<td>Canny</td>
<td>Using probability for finding error rate</td>
<td>Complex Computations and False Zero Crossing</td>
</tr>
</tbody>
</table>

IV. METHOD TO EVALUATE THE PERFORMANCE OF EDGE DETECTORS

The importance of performance evaluation is recognized in the computer vision community [13]. Predicting the performance in an image-understanding task of practical value, however, is difficult. The method used to evaluate the performance of edge detectors is to measure the quality of edge detectors using signal to noise ratio and mean square error between the edge detectors images and the original image.

The method is borrowed from digital signal processing and information theory, and provide with the equations that can be used to measure the amount of error in a processed image by comparison to known image [14].

The evaluation of edge detection performance obeys the three important criteria. First, the edge detector should find all real edges and not find any false edges. Second, the edges should be found in the correct place. Third, there should not be multiple edges found for a single edge.

The experiment is done with 10 different kinds of the IR image of the image scale 256x256. The original IR image has been taken and the salt pepper noise is added to it. Then an edge detection operator is applied to the images to detect the edges.

The PSNR values are obtained by calculating signal to noise ratio peak and the root mean square error between the edge detection images and the original grayscale image. The original ground truth image is compared with the different edge detect operators for the original grayscale noisy image without filter and with different filters such as Median, Lee and Kuan. A commonly used metric for image quality assessment are Peak Signal to Noise Ratio (PSNR), root-mean-square error, εMS, and the root-mean square signal-to-noise ratio, SNR_RMS which originated from signal theory [15]. The values are calculated using the equations (1), (2) and (3) respectively.

\[
\varepsilon_{MS} = \frac{1}{MN} \sum_{r=0}^{M-1} \sum_{c=0}^{N-1} [E(r,c) - O(r,c)]^2
\]
\[
\text{SNR}_{RMS} = \frac{1}{\frac{1}{MN} \sum_{r=0}^{M-1} \sum_{c=0}^{N-1} [E(r,c)]^2 - \frac{1}{(L-1)^2} \sum_{r=0}^{M-1} \sum_{c=0}^{N-1} [E(r,c) - O(r,c)]^2}
\]
\[
\text{SNR}_{PSNR} = 10 \log\left( \frac{1}{\frac{1}{MN} \sum_{r=0}^{M-1} \sum_{c=0}^{N-1} [E(r,c) - O(r,c)]^2} \right)
\]

Where O(r, c) is the original image, E(r, c) is the reconstructed image and L is the number of gray level equal to 256.

V. RESULTS AND FINDINGS

On the behavioral study of these edges with respect to the following differentiation operators such as Sobel, Prewitt, Log and Canny the comparison of the PSNR values shows that the Sobel method is the best in finding the edges of noisy IR images. IR images are taken and salt and pepper noise with 10% for both the salt and pepper are added to it.

Then the noisy images are applied to the edge detection operators, the PSNR and RMSE values are found as the difference between the original image and the edge-detected images. The results are found that, among the four edge detectors the Sobel edge detector is the best.

Then all the three filters are applied to noisy IR images to remove the noise in it. After applying the filters to the images, the edge detector operator is applied to all kinds of filtered images. Then PSNR value is calculated between the original image and filtered edge detected images. The results are founded that Sobel operator detector performs well with the median filter, when compared to the other types of the filters. The following table and the graph show the performance of the Sobel operator with the Median filter.

Table (2) gives the Comparison of the PSNR values for the Sobel Operator between the Noisy IR Images and the Filtered Images using Median Filter.

<table>
<thead>
<tr>
<th>Images</th>
<th>Before Filtering</th>
<th>After Filtering</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.8174</td>
<td>6.9886</td>
</tr>
<tr>
<td>2</td>
<td>9.0936</td>
<td>12.4772</td>
</tr>
<tr>
<td>3</td>
<td>7.1016</td>
<td>8.4399</td>
</tr>
<tr>
<td>4</td>
<td>7.8774</td>
<td>8.7133</td>
</tr>
<tr>
<td>5</td>
<td>3.5385</td>
<td>3.6662</td>
</tr>
<tr>
<td>6</td>
<td>7.8216</td>
<td>8.5315</td>
</tr>
<tr>
<td>7</td>
<td>6.4154</td>
<td>7.0983</td>
</tr>
<tr>
<td>8</td>
<td>8.7325</td>
<td>8.9352</td>
</tr>
<tr>
<td>9</td>
<td>6.4414</td>
<td>9.1561</td>
</tr>
<tr>
<td>10</td>
<td>7.7131</td>
<td>9.8801</td>
</tr>
</tbody>
</table>
VI. CONCLUSION

In this paper, evaluation of different edge detection operators are applied for the noisy IR images and its quality is compared before filtering and after filtering. The edge detectors chosen for the study are Sobel, Prewitt, Log and Canny. Out of four operators, Sobel edge detection method is found as the best in detecting the edges in a noisy IR images. By applying all three filters to the noisy images, to the noise are removed from the images and then Sobel operator is applied to all the filtered images. Among all the three filters Median, Lee and Kuan that are applied to the noisy IR images, the Median filter performs well for the Sobel edge detection operator. So the paper concludes that Sobel edge detector with the Median filter performs well in detecting the edges, when compared to other edge detector and filters.

References: