Highly-Performed Fuzzily-logicized Edge Detecting Algorithm for Noisy Handwritings

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Abstract:
The main targets for using the edge detection techniques in image processing are to reduce the number of features and find the edge of image based-contents. In this paper, comparisons have been demonstrated between classical methods (Canny, Sobel, Roberts, and Prewitt) and Fuzzy Logic Technique to detect the edges of different samples of image's contents and patterns. These methods are tested to detect edges of images that are corrupted with different types of noise such as (Gaussian, and Salt and pepper). The performance indices are mean square error and peak signal to noise ratio (MSE and PSNR). Finally, experimental results show that the proposed Fuzzy rules and membership function provide better results for both noisy and noise-free images.

Keywords: Classical edge detection, Edge detection, Fuzzy logic, Image noise, Image processing.

Introduction:
The edge detection used to find the boundary pixels of objects resident in the image in order to reduce the data of features. There are classical methods used generally to find the edges of image contents (Sobel, Canny, Roberts, and Prewitt) and these methods usually operate depending on a pair of convolution kernels (3x3) [1,2]. These kernels are used to convolve the image by moving the mask kernel over pixels with respect to the center of mask represented as pivot pixel for other eight neighbor pixels. Below, definition equations and operators concepts for classical methods are presented.

Sobel Operator:
This operator consists of the following convolution kernel. The kernel is used by applying for an image and get measurements of the gradient in both orientations (Gx and Gy) and these components combined to produce the magnitude of the gradient in any neighborhood pixel. In equ.(1) is the form of gradient magnitude is given by following [3]

\[ |G| = |G_x| \cdot |G_y| \]  

The convolution kernel of Sobel operator is shown in Table-1.

Table 1–Convolution kernel of Sobel operator

| 1 | 0 | 1 |
|---|---|---|
| 2 | 0 | 2 |
| 1 | 0 | 1 |

Canny operator:
Canny operator[4] has three criterions as described below.

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- Convolves an image \( f(m,n) \) by applying a Gaussian function.
- Find edge strength, and gradient strength at each point.
- Find edge direction.
- Relate the edge direction to trace an image.
- Apply non-maximum suppression for gradient magnitude image.
- Apply two thresholds \( Th1 > Th2 \), if magnitude > \( Th1 \) then output is edge, else if magnitude > \( Th2 \) then candidate.
- Hysteresis: Find all the candidates located in neighbors in gradient direction. In equ.(2) and equ.(3) is the formula of the Canny operator.

\[
g(m,n) = G(m,n) \ast f(m,n) \quad (2)
\]

\[
G_\sigma = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{m^2+n^2}{2\sigma^2}\right] \quad (3)
\]

Where \( m \) and \( n \) represents current pixel of image, \( \sigma \) is relative to the highest value of the gradient magnitude of the image.

**Robert operator:**

This operation is measured as uncomplicated calculation which is 2D spatial gradient moves over an image. The output values of the pixels get from this operator represented the probable absolute magnitude of the spatial gradient of the input image at that point. This operator has consists convolution kernel of \((2\times2)\) as shown in Table-2 [5].

**Table 2-Convolution kernel of Robert operator**

|     | 0   | 1   |
|-----|-----|-----|
| 1   | 0   | -1  |
| 0   | -1  | 0   |

**Prewitt Operator:**

This operator is used to detect both sides of edge vertically and horizontally in an image. The convolution kernel has designed as \((3\times3)\) to detect gradient in both sides as shown in Table-3 [6].

**Table 3-Convolution kernel of Prewitt operator**

|     | 0   | +1  |
|-----|-----|-----|
| +1  | +1  | +1  |
| -1  | 0   | 0   |
| -1  | -1  | -1  |

**Fuzzy logic for edge detection:**

One of the recent techniques that are used for edge detection in image processing is fuzzy logic [7,8,9]. This kind of technique is attractive to researchers because it can deal with image processing uncertainties[10]. The detection procedure has three stages that are determined as image data (coding and decoding). In this paper, Fuzzy membership functions that represent input and output are triangles[11], many membership functions of different shapes were tested, the ones that give the satisfactory performance are shown in Figure-1.

![Fuzzy logic for edge detection](image-url)
The proposed design of FIS consists of four inputs and one output. The inputs are represented as (P1, P2, P3, and P4) that represents the pixel values of convolution kernel (2x2) as shown in Table-4 [12].

**Table 4-Convolution kernel for input and output**

| P1 | P2 | P3 | P4 out |
|----|----|----|--------|

**Proposed system:**

In this proposed approach, fuzzy algorithm basically has the usual fuzzy logic steps as some fuzzy edge detection approaches that are mentioned earlier. We've improved the detection of edges found in the image by selecting different membership functions, especially for the output. The selection of output membership functions is very important because of uncertainties that appear in images such as noise. Therefore, it is important to choose a suitable membership function and yet a fuzzy edge detection system that can distinguish between real edges and noise pixels. The main purpose is to design an edge detection system that can extract edges.

**Results Analysis:**

The test images are handwritten signatures which have a variety of contents (curves, angles, smooth line and hard line) for testing the proposed work. In the first phase (preprocessing), the input image is converted to grayscale which takes less time of processing than color format, in addition, a rescale has done on the grayscale image to fix size (256x256). Table-5 depicts the original noise free image samples and those samples after adding “Gaussian and Salt and Pepper noise”.

**Table 5-Original noise free and noisy image samples**

| noise | Sample 1 | Sample 2 |
|-------|----------|----------|
| Original noise free | ![Sample 1](image1.png) | ![Sample 2](image2.png) |
| Gaussian | ![Sample 1](image3.png) | ![Sample 2](image4.png) |
| Salt & Pepper | ![Sample 1](image5.png) | ![Sample 2](image6.png) |

The performances of classical edge detection methods and fuzzy logic method are compared and
tested first for noise free images. Then two types of noise are added to image samples and the edge detection performances are evaluated using “Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR)”. Informatics metric MSE and PSNR equations are described in formulas (4 and 5) respectively.

\[
MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i, j) - K(i, j)]^2 \tag{4}
\]

\[
PSNR = 10 \cdot \log_{10} \left( \frac{\text{max}^2}{MSE} \right) \tag{5}
\]

Where i and j represent a current pixel of image, m and n represent height and width. I is the source image and K is the image compared with.

Table-6 shows the edge detection results for free of noise images. It is clear that fuzzy technique produces clearer and brighter edges as compared to conventional methods results.

| Method       | Sample 1 | Sample 2 |
|--------------|----------|----------|
| Sobel        | ![Sobel](image1) | ![Sobel](image2) |
| Canny        | ![Canny](image3) | ![Canny](image4) |
| Prewitt      | ![Prewitt](image5) | ![Prewitt](image6) |
| Roberts      | ![Roberts](image7) | ![Roberts](image8) |
| Fuzzy logic  | ![Fuzzy logic](image9) | ![Fuzzy logic](image10) |

Edge detection of images corrupted with Gaussian noise edge detection of images:

Gaussian noise of zero mean and 0.001 variance has been applied to the same image samples, in edge detection phase, a comparison between classical four types and fuzzy logic approach is depicted in Table-7.
Table 7-Edge detection of images corrupted with zero mean and 0.001 variance Gaussian noise.

| Method     | Sample 1                                      | Sample 2                                      |
|------------|-----------------------------------------------|-----------------------------------------------|
| Sobel      | ![Sobel](image)                                | ![Sobel](image)                                |
| Canny      | ![Canny](image)                               | ![Canny](image)                               |
| Prewitt    | ![Prewitt](image)                             | ![Prewitt](image)                             |
| Roberts    | ![Roberts](image)                             | ![Roberts](image)                             |
| Fuzzy logic| ![Fuzzy logic](image)                         | ![Fuzzy logic](image)                         |

From the table we conclude that the system couldn’t remove Gaussian noise, however, the edge detection process produces clearer edges as compared to classical techniques. Finally, an informatics metric has been calculated to find the performance of proposed and classical methods. The comparison has been used on both noisy and free noise samples of images and between classical methods (Canny, Sobel, Prewitt, and Roberts) and fuzzy logic. The performance of the edge detection process is evaluated using MSE and PSNR and compared for classical methods and fuzzy logic method. The results are depicted in Table-8 contents the MSE results, and Table-9 contents PSNR results. The results show that Sobel method gives the lowest MSE and highest PSNR among other methods. However fuzzy edge detection technique produces the brighter visual appearance as shown in Table-8.

Table 8-The MSE of edge detection methods for images methods for images corrupted with Gaussian noise.

| Methods   | MSE sample 1 | MSE sample 2 |
|-----------|--------------|--------------|
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Table 9-The PSNR of edge detection methods for images corrupted with Gaussian noise.

| Methods   | PSNR sample 1 | PSNR sample 2 |
|-----------|---------------|---------------|
| Sobel     | 71.0469       | 77.0231       |
| Canny     | 67.3984       | 80.9865       |
| Prewitt   | 69.6214       | 76.6334       |
| Roberts   | 69.7596       | 75.8034       |
| Fuzzy logic | 67.7404     | 72.7163       |

Edge detection of noisy images:
The previous tests are repeated with a different type of noise which is called “salt and pepper”. The results of edge detection of images corrupted with this noise of density 0.0045 (which means that 0.45% of the image is corrupted) are shown in Table 10. The results of Table 10 clearly pointing the superiority of the proposed filters to those of conventional ones that are sensitive to noise.

Table 10-MSE for edge detection when adding salt and pepper noise of density 0.0045 to images

| Methods   | MSE Sample 1 | MSE Sample 2 |
|-----------|--------------|--------------|
| Sobel     | 0.0926       | 0.0844       |
| Canny     | 0.1824       | 0.1788       |
| Prewitt   | 0.1543       | 0.1481       |
| Roberts   | 0.0491       | 0.0431       |
| Fuzzy Logic | 0.0017     | 9.46e-04     |

The fuzzy method produces better edge detection without the need for filtering the noise before edge detection process. Informatics metric MSE and PSNR for both classical and fuzzy logic for sample images are discussed in Tables (11 and 12) where Salt and Pepper noise filter applied with density 0.0045. Then the performances of the previous methods were tested by increasing the added salt and pepper noise density to 0.045 which means that 4.5% image is corrupted. The MSE and PSNR results are shown in Tables (13 and 14).

Table 11-Edge detection of images corrupted with salt and pepper noise with density 0.0045 to images.
| Method       | Sample (1) | Sample (2) |
|--------------|------------|------------|
| Sobel        | ![Image](image1) | ![Image](image2) |
| Canny        | ![Image](image3) | ![Image](image4) |
| Prewitt      | ![Image](image5) | ![Image](image6) |
| Roberts      | ![Image](image7) | ![Image](image8) |
| Fuzzy logic  | ![Image](image9) | ![Image](image10) |

**Table 12** - PSNR for edge detection when adding 0.0045 noise density to images

| Method       | PSNR sample 1 | PSNR sample 2 |
|--------------|---------------|---------------|
| Sobel        | 68.1800       | 68.4789       |
| Canny        | 63.8493       | 64.2000       |
| Prewitt      | 65.5472       | 65.6363       |
| Roberts      | 71.0276       | 71.3653       |
| Fuzzy logic  | 84.2544       | 90.2750       |

**Table 13** - MSE for edge detection when adding 0.045 noise density to images

| Methods      | MSE sample1  | MSE sample2  |
|--------------|--------------|--------------|
| Sobel        | 0.0099       | 0.0092       |
| Canny        | 0.0268       | 0.0247       |
| Prewitt      | 0.0181       | 0.0178       |
| Roberts      | 0.0051       | 0.0047       |
| Fuzzy logic  | 2.44e-04     | 6.10e-05     |

**Table 14** - PSNR for edge detection when adding 0.045 noise density to images
The evaluation shows that fuzzy logic method produces the lowest MSE and highest PSNR among other edge detection methods for both noise densities. This means that fuzzy logic technique can detect edges of images corrupted with salt and pepper noise without the need to use filters to remove the noise from the image before the edge detection process.

Conclusion:
Fuzzy logic method produces bright and clear edge detection results for noisy images while classical methods couldn't give such good results because classical methods consider noise pixels as edges found in the image. Finally, comparison of the above results leads to the conclusion that fuzzy logic method can utilize the benefits of the Gaussian filter to give smooth and bright edges as shown clearly while classical methods could not detect the edges in such a good way. In general, fuzzy logic edge detection technique proves to be an effective edge detection method with a superior performance to that of the compared classical edge detection methods.

Future work:
The future work will be extended the presented 2D edge filtering model to be developed for a 3D grayscale edge filtering model [14-18] and 4D color edge filtering model for advanced bio imaging applications [19]. A breakthrough approach for handwritten alphabet machine recognition may be achieved via fuzzy entropy [20] and real-time character recognition algorithm [21].

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| Method     | PSNR sample 1 | PSNR sample 2 |
|------------|---------------|---------------|
| Sobel      | 58.4661       | 58.8695       |
| Canny      | 55.5197       | 55.6068       |
| Prewitt    | 56.2483       | 56.4256       |
| Roberts    | 61.2159       | 61.7853       |
| Fuzzy Logic| 75.8424       | 78.3717       |
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