Fuzzy Logic Based Edge Detection for Noisy Images

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Abstract—Edge detection is low level image processing tool and has useful applications in the field of pattern recognition and machine vision. A fuzzy logic based edge detection algorithm is proposed in this paper, to detect edges in gray scale images. Fuzzy logic is very helpful in edge detection because it can handle the problem of decision making in partially true and partially false values in between completely true and completely false values. The proposed algorithm consists of a window mask and fuzzy inference system. The values obtained from the window mask are subjected to fuzzy rules developed for edge detection. The developed edge detection algorithm was successfully tested on both noise free and noisy images. The results are compared with other traditional edge detection techniques, like Sobel, Prewitt, Roberts, Laplacian of Gaussian (LOG) and previously developed fuzzy logic based edge detection technique. The proposed algorithm was tested on a gray scale standard image of 512 x 512 pixels having salt and pepper noise of 25 dB noise level. The proposed algorithm have detected 202 false edge pixels in noisy image, in comparison with the other reported edge detection techniques such as Prewitt (9395), Sobel (6673) Roberts (4792), LOG (1241) and previously developed fuzzy logic technique (5362) respectively. Consequently, we have proposed and demonstrated a fuzzy logic based method, which provides better solution to edge detection problem in noisy images.

Keywords— Fuzzy Logic, Image Processing, Edge Detection

I. INTRODUCTION

Edge detection is a low level image processing tool and it has widespread applications that range from pattern recognition to computer vision. Edges (in the image) differentiate various regions present in the image and contain useful information about the object (of interest) in the image. Edge detection is a difficult task and highlights the high frequency components in the image. It becomes more arduous when it comes to noisy images. Noise and the true edges present in the image contain a high frequency component, that’s why edge detection in these images mostly results in false edge detection or missing true edges [i].

The general method employed for edge detection is a linear time invariant filters that also take little computation time. An edge in case of linear filters is considered as a sudden change in the gray scale value of the neighborhood pixels. The edge detection techniques such as Sobel [i], Roberts [ii], LOG [iii], Laplacian [iv], Prewitt [v-vi] techniques corporate the idea of spatial differential filters, where edges are detected by using local gradient operators. The computation time of these operators are very low. However, they are sensitive to noise and blurred edges. A novel scan line approximation based edge detection algorithm is reported in [vii]. The segmentation quality and the computational cost of the reported algorithm are far better in comparison to other region based segmentation techniques. Edge detection technique for automatic graphical inspection utilizing mathematical and logic procedures was proposed in [viii]. To detect edges in the noisy images Genming and Bouzong [ix], developed a 5x5 window mask. The developed algorithm does not rely on a fixed threshold value and is therefore proficient in detecting edges in a non uniform grayscale background.

The concept of fuzzy emerged as a useful tool for edge detection in recent years [x-xii]. Fuzzy logic is a mathematical logic that is based on approximate reasoning rather than exact and crisp value. It can handle the problem of decision making in partially true and partially false values between completely true and completely false values. Thus it provides extra intelligence and practical means to problem solving [xiii]. Kim et al. [xiv] applied the concept of fuzzy logic to edge detection in images. The developed algorithm uses a 3x3 window mask and a look up table for edge detection. The algorithm is useful for edge detection in dynamic environment as it does not depend on manual threshold adjustment. Kaur et al. [xv] developed a fuzzy logic rule base method for edge detection. The developed algorithm is based on sixteen fuzzy rules. Their proposed algorithm was accurate in detecting edges; however the algorithm is sensitive to noise. Khan and Thakur [xvi] proposed an efficient fuzzy logic based edge detection technique. The developed edge detection technique is based on fuzzy rules and utilizes a 2x2 window mask. The algorithm is efficient in edge detection however again it is sensitive to noise. In this study fuzzy logic based edge detection algorithm for noisy images is proposed. The proposed algorithm is based on a 3x3 window mask and fuzzy rules. The window mask and fuzzy rules are defined in a manner such as to detect edges in both noise free and noisy images.

The remaining of the article is organized as following. Section II presents the proposed methodology for edge detection, followed by experimentation and results.
followed by discussion in section III. Finally, conclusions are drawn in section IV.

II. PROPOSED METHODOLOGY

The proposed algorithm for edge detection in images is based on fuzzy inference system. A 3x3 window mask is designed that takes the intensity values of the pixels from the image and preprocess it. A fuzzy inference system is designed that takes these processed values as input. These values are subsequently converted into the fuzzy plane. A fuzzy rule base is defined that determine and show the edge pixels in the output image. The output of the system is calculated based on centroid method and defuzzification is performed based on Mamdani implication. Block diagram of the proposed methodology is shown in Fig. 1.

Fig. 1. Block diagram of the proposed image edge detection technique.

A. Window Mask

In the proposed method a 3x3 window mask is designed for scanning the image. The mask takes the intensity values, \( S_i \) of eight neighborhood pixels with the central pixel, \( S_0 \) as the out pixel as shown in Fig. 2.

\[
\begin{array}{ccc}
S_1 & S_2 & S_3 \\
S_4 & S_0 & S_5 \\
S_6 & S_7 & S_8 \\
\end{array}
\]

Fig. 2. Window mask for scanning the image.

The intensity values obtained from the mask are preprocessed prior applying to the fuzzy inference system. The processed mask is shown in Fig. 3.

Where \( \Delta S_i = |S_i - S_o| \) for \( i = 1, 2, 3, \ldots, 8 \).

\[
\begin{array}{ccc}
\Delta S_1 & \Delta S_2 & \Delta S_3 \\
\Delta S_4 & S_0 & \Delta S_5 \\
\Delta S_6 & \Delta S_7 & \Delta S_8 \\
\end{array}
\]

Fig. 3. Processed window mask.

B. Fuzzy Membership Functions

Membership functions (MFs) play important role in fuzzy logic. They are the key ingredients of the fuzzy set theory and they calculate the fuzziness in the fuzzy set. As the MFs have effects on the fuzzy inference system, therefore the type and shape of the MF should be selected carefully based on the nature of problem. For the proposed edge detection algorithm Trapezoidal MFs are used for the input data, as they show comparatively better are widely being used [xvii-xiii], while Gaussian MFs are used for the output data, as they have the advantage of being smooth and non-zero at all points.

The standard trapezoidal MF [xix] is expressed mathematically as in (1).

\[
T_{rzF}(z; p, q, r, s) = \begin{cases} 
0 & (z < p) \text{or}(z > s) \\
(z - p) & p \leq z \leq q \\
q - p & q \leq z \leq r \\
1 & r \leq z \leq s \\
\end{cases}
\]

(1)

Where \( p, q, r \) and \( s \) are the different parameters of trapezoidal MF and its details are shown Fig. 4(a).

The Gaussian MF [xx] is express in equation (2)

\[
GF(z; m, c) = e^{-\frac{(z-m)^2}{2c^2}}
\]

(2)

where \( m \) and \( c \) are parameters of the Gaussian MF and its details are depicted in Fig. 4 (b).
C. Fuzzy Sets

Each input, $\Delta S_i$, to fuzzy system is divided into two fuzzy sets, Low and High. The output (pixel), $S_0$ from the fuzzy system is also divided into two fuzzy sets, Non-Edge and Edge. The associated membership functions with the input and output fuzzy sets are shown in Fig. 5 and Fig. 6 respectively.

Different parameters and terminologies of both input and output fuzzy sets are listed in Table I.

![Fig. 4. (a) Trapezoidal membership, (b) Gaussian Membership.](image)

![Fig. 5. Membership functions of the input variable $\Delta S_i$ to the fuzzy system.](image)

![Fig. 6. Membership functions of the output pixel $S_i$ from the fuzzy system.](image)

### Table I. Parameters of Fuzzy Inference System

<table>
<thead>
<tr>
<th>MF Type</th>
<th>Variable</th>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Input $\Delta S_i$</td>
<td>Low</td>
<td>[0 25 75]</td>
<td>[0 255]</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>[25 75 255 255]</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Output $S_0$</td>
<td>Gaussian</td>
<td>Non-Edge</td>
<td>[3.5 10]</td>
</tr>
<tr>
<td></td>
<td>Edge</td>
<td>[3.5 245]</td>
<td>[0 255]</td>
</tr>
</tbody>
</table>

D. Proposed Fuzzy Rule Base

In fuzzy inference system, fuzzy rule base or knowledge base is a set of linguistic descriptions [xxi]. They play an important role as they make decision related to categorizing an input or adjusting and stabilizing the output. Fuzzy rule base for the proposed edge detection algorithm consists of the following linguistic descriptions as listed in Table II.

III. RESULTS AND DISCUSSION

The proposed edge detection method was tested on greyscale images. The method was capable of detecting all edges in a greyscale images. This was proved by finding edges in a couple of greyscale images (rainbow and flower) through the proposed edge detection technique as shown in Figure 7. Figure 7 (a & b) shows original (greyscale) rainbow and flower images of size $314 \times 192$ pixels in which there are six boundary lines in between five distinct gray scale regions. The developed algorithm has successfully detected these six boundary lines (edges) as shown in Figure 7 (c). Similarly, the proposed method has successfully detected edges in greyscale flower image of $225 \times 225$ pixels as shown in Figure 7 (d).

One of the advantages of the proposed method is that it can detect edges in noisy images as well. This was confirmed via adding 'salt and pepper' noise at a level of 25
dB to the input image. In order to calculate the values of peak signal to noise ratio (PSNR), first the mean square error (MSE) is calculated based on equation (3) [xxii-xxiii].

\[
MSE = \frac{1}{MN} \sum_{y=1}^{N} \sum_{x=1}^{M} [F_1(x, y) - F_2(x, y)]^2
\]  
(3)

where \(F_1\) indicates the noise free image and \(F_2\) indicates noisy image. \(M\) and \(N\) respectively denote the number of rows and columns of the given images. The equation for the measurement of Noise level (PSNR) becomes as in (4)

\[
PSNR = 10 \log_{10} \left( \frac{Q^2}{MSE} \right)
\]  
(4)

where \(Q\) represents the maximum possible pixel value of the input image. For eight bit unsigned integer data type image, the value of \(Q\) is equal to intensity level 255.

The proposed edge detection algorithm is applied to a standard gray scale image of 512 x 512 pixels having 25 dB salt and pepper noise. The results are shown and compared with other reported edge detection techniques as shown in Fig 8 and Fig.9. The experimental results show that the proposed fuzzy logic based edge detection technique has detected a few false edge pixels in comparison with the other reported edge detection techniques. In Fig. 9 it is clear that the proposed edge detection algorithm has detected 202 false edge pixels, when subject to a noisy image of 512 x 512 size and 25 dB noise level, while other edge detection techniques like Prewitt, Sobel, Roberts, LOG and

### TABLE II. Fuzzy Rule Base for the Proposed Edge Detection Algorithm

<table>
<thead>
<tr>
<th>Rules</th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\Delta S_1)</td>
<td>(\Delta S_2)</td>
</tr>
<tr>
<td>R1</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>R2</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>R3</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>R4</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>R5</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>R6</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>R7</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>R8</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>R9</td>
<td>High</td>
<td>High</td>
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<tr>
<td>R10</td>
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<tr>
<td>R11</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>R12</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Fig. 7. The results of the proposed edge detection algorithm, (a) Original rainbow image, (b) original flower image, (c) edge detected in rainbow image, (d) edge detected in flower image.
previously developed fuzzy logic technique, have detected 9395, 6673, 4792, 1241 and 5362 false edge pixels respectively.

Fig. 8. Results of the edge detection after applying different edge detection techniques, (a) original image, (b) noisy image, (c) edge detection by Sobel, (d) edge detection by Robert, (e) edge detection by previously developed fuzzy logic technique [xiv], (f) edge detection by the Prewitt, (g) edge detection by log operator, (h) Our method.

Fig. 9. False edge detected pixels in a standard image of 512 x 512 pixels having 25 dB noise level by different edge detection algorithms.

IV. CONCLUSION AND FUTURE WORK

Fuzzy logic based edge detection algorithm is developed and reported in this paper. The algorithm was tested on (both noise free and noisy) grayscale images of size 512x512 pixels. The proposed method has successfully detected all the edge pixels in noise free and noisy grayscale images. The method was also compared with other established fuzzy logic based edge detection techniques. The value of added noise (salt and pepper noise) is of 25 dB. The proposed algorithm has detected 202 false edge pixels in the noisy image, that is a very low value in comparison with the other reported edge detection techniques like Prewitt, Sobel, Roberts, LOG and previously developed fuzzy logic technique, which have detected 9395, 6673, 4792, 1241 and 5362 false edges pixels respectively. The experimental results indicate that the developed algorithm provides better solution to edge detection problem in noisy images.

In future work, an investigation on how the proposed method could be extended to clinical examination of noisy Magnetic Resonance Images MRI for edge detection is currently under consideration.

REFERENCES


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